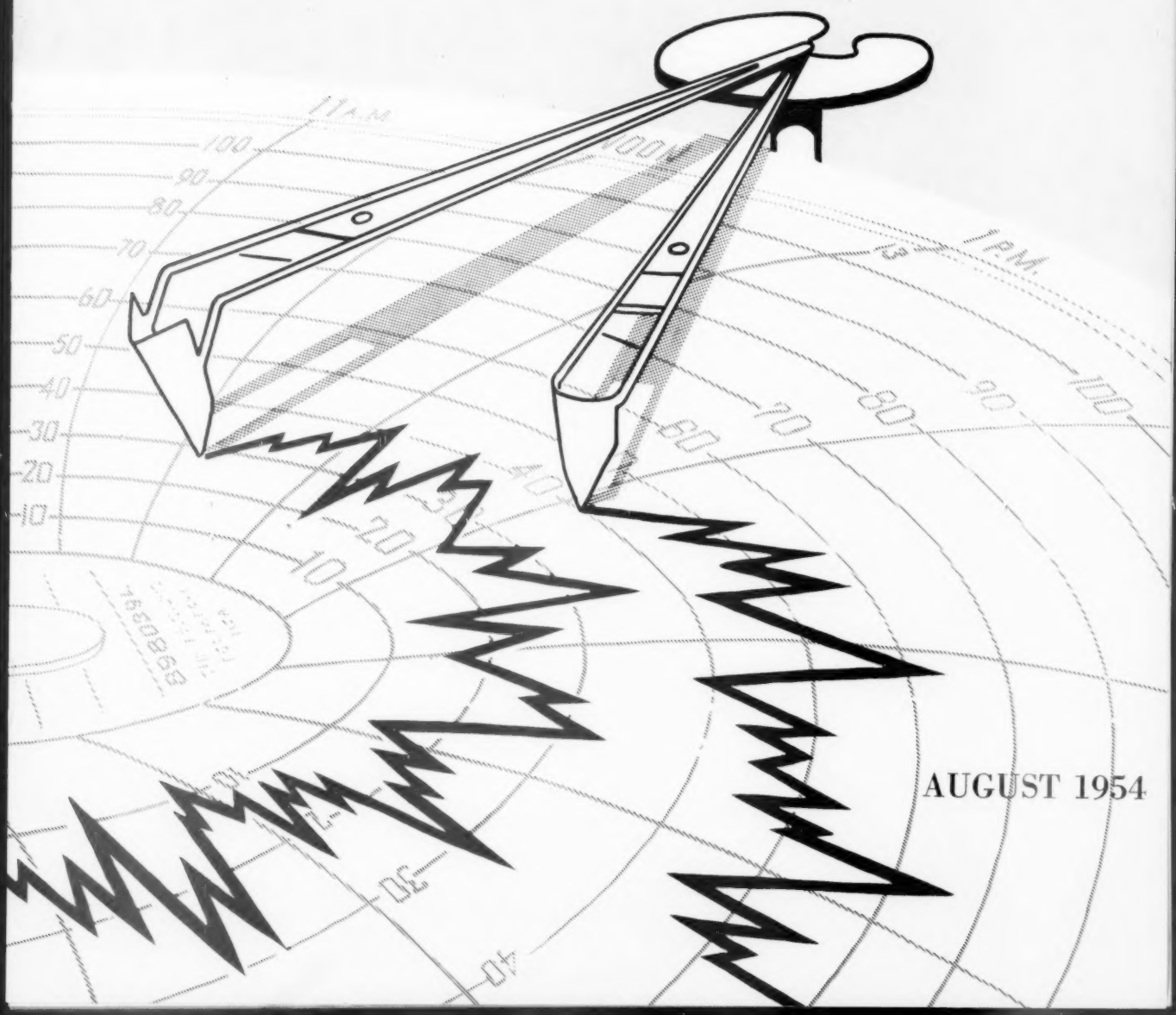
JOURNAL OF

PETROLEUM TECHNOLOGY

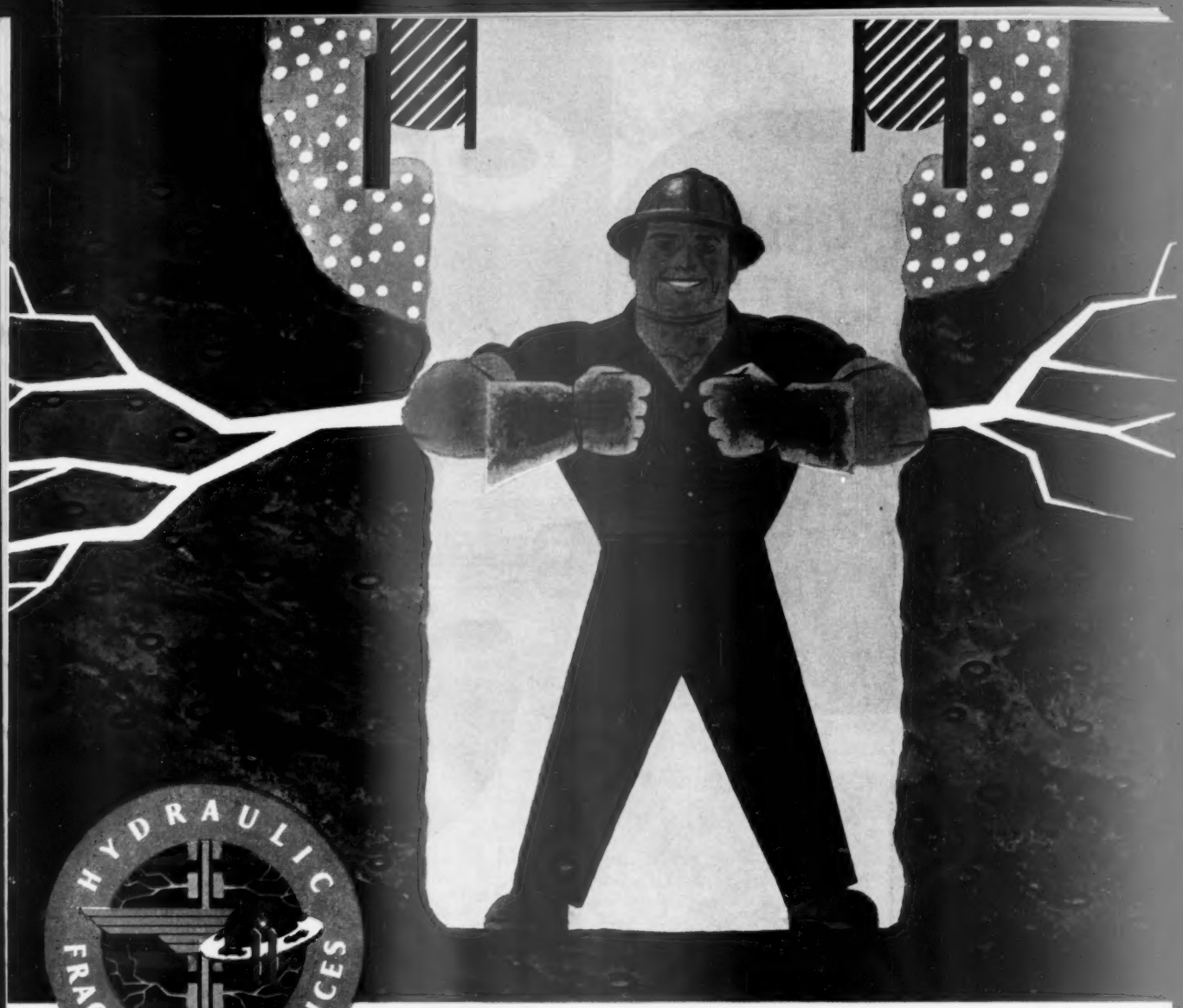


AUGUST 1954

OIL MEANS HEATING

The baker's oven . . . heat for our homes . . . the foundry's furnace . . . ship's engines . . . are fired with energy from petroleum. Every few minutes, night and day throughout the year, a Schlumberger crew completes another operation for the oil industry. This wealth of experience is assurance that you will receive the best in men and materials when you call Schlumberger.

. . . and Schlumberger means Service



Samson

OF THE BIG FRAC

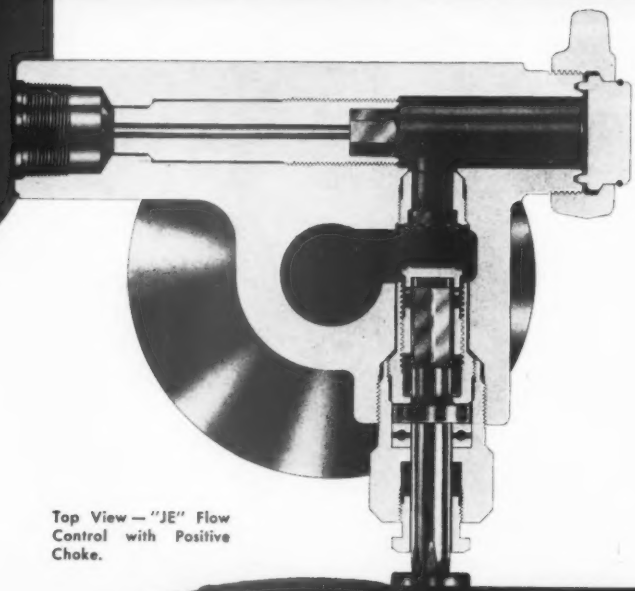
Giants roam the earth these days . . . Samsons of horsepower whose great strength is harnessed to a new production improvement technique. This process is called the "big frac", field-name for high volume formation fracturing. Halliburton pioneered this important service. For over five years Halliburton's huge red and silver fracturing equipment has been a familiar sight in the oil fields. It set a remarkable record—3 out of 4 wells fractured have increased initial production, obtained a more favorable PI, and improved sustained production. This success has come not only from proper equipment but from wide experience as well—priceless experience on more than 35,000 fracturing jobs that is Halliburton's alone. Knowing when, where, and how to use the Samson of the big frac make Halliburton first choice for this important production improvement technique.

HALLIBURTON OIL WELL CEMENTING COMPANY
DUNCAN, OKLAHOMA

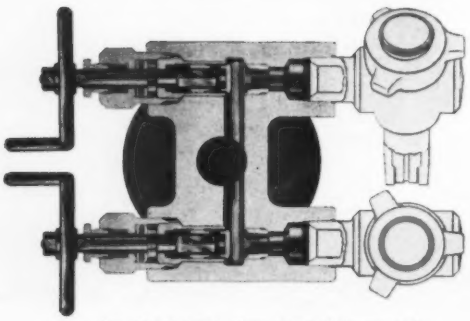
PERPETUAL PROGRESS IN PRODUCTION IMPROVEMENT TECHNIQUES

O·C·T "JE" FLOW CONTROLS

THE ONLY FLOW CONTROL ON THE MARKET THAT GIVES YOU A CHOKE AND A VALVE*



Top View — "JE" Flow Control with Positive Choke.



The O-C-T Dual Flow Control is an outstanding companion to the "JE" Flow Control units which have gained universal acceptance in oilfields all over the world. This unit replaces 13 different fittings.

It's the best seller BECAUSE It's the best buy

*Yes, this compact, easy-operating O-C-T "JE" Flow Control Unit . . . adaptable to either positive or adjustable chokes . . . is the only flow control on the market today that gives you the full advantages of both a choke and a true valve type gate assembly and seating arrangement. The valve in your O-C-T Flow Control Unit is a complete valve type gate assembly . . . with ball bearing construction to assure easy, quick operation. When you buy your next trees . . . regardless of the make . . . be sure to specify O-C-T "JE" Flow Controls. More trees of all makes are now topped with O-C-T "JE" Flow Controls than all other makes . . . because O-C-T "JE" Flow Controls give you greater dependability, easier operation and save as much as $300.00 per tree over a conventional tree wing. Available through more than 700 supply store locations.

Oil Center Tool Co.

P. O. BOX 3091, HOUSTON, TEXAS

Export Representatives: Sterling Areas — Le Grand, Sutcliff & Gell, Ltd., Rochester, Kent, England. Address Export Inquiries for All Other Countries to P. O. Box 3091, Houston, Texas.

JOURNAL OF PETROLEUM TECHNOLOGY

AUGUST, 1954

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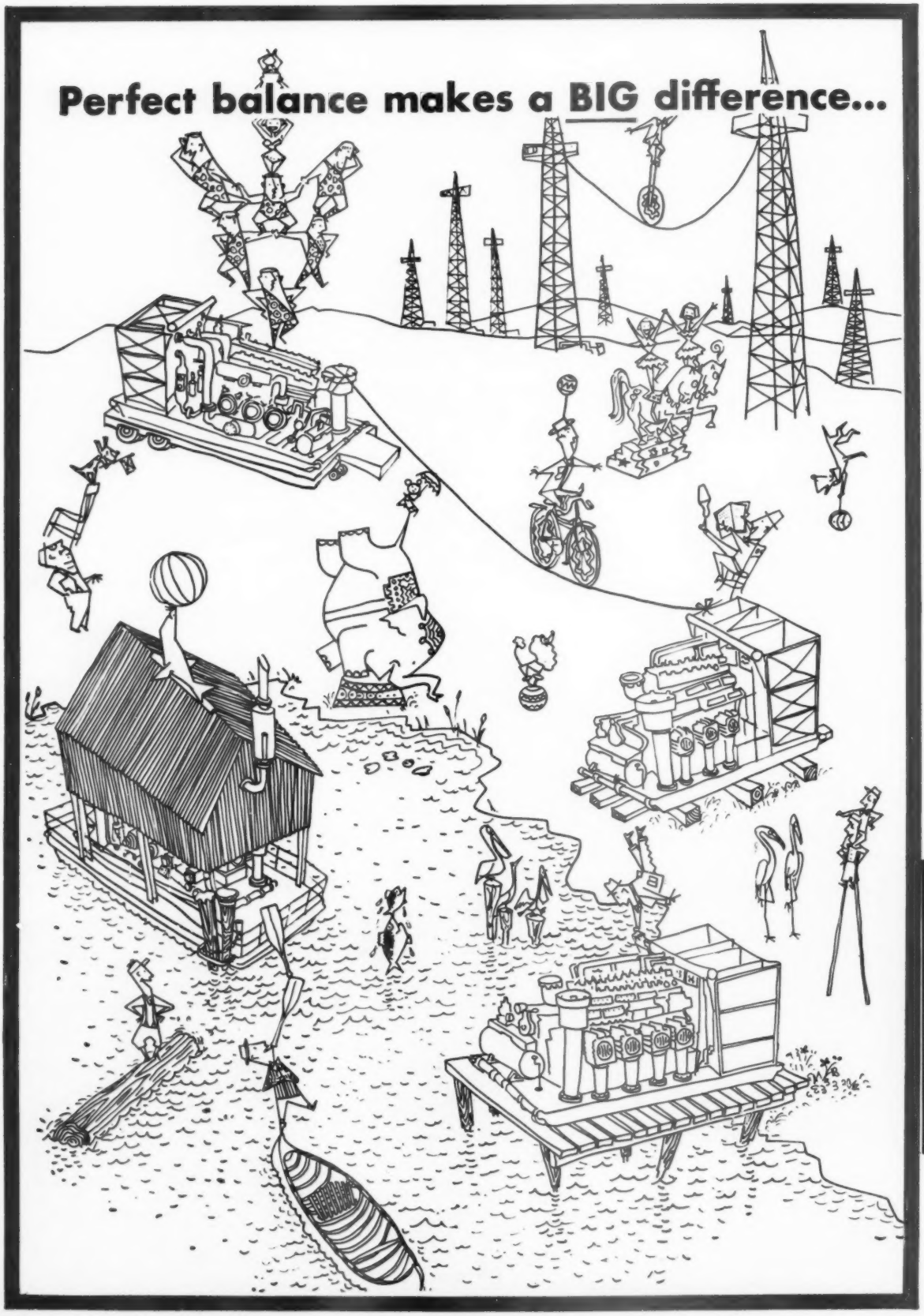

Perfect balance makes a BIG difference...

Clark "Midget Angles"

can be operated ANYWHERE

on trailers, timbers, piles, barges

There's no problem about *where* or *how* to install a Clark Midget Angle. Because it has perfect balance — virtually *vibrationless operation* — it can be put to work anywhere. No large, expensive foundations are needed.

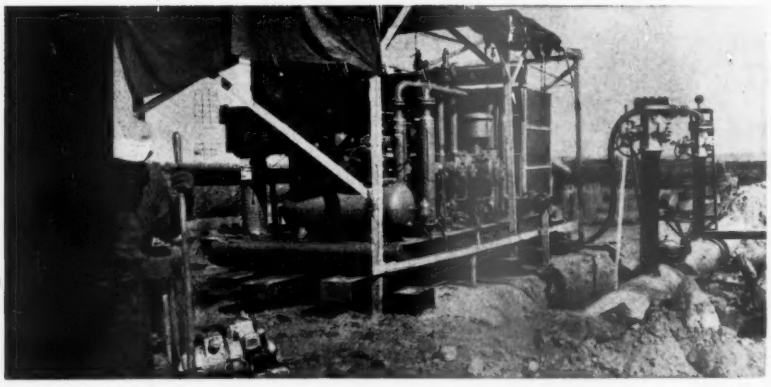
On timbers, piles, barges, trailers, swampland, steel framework . . . *you* name it . . . a Midget Angle is ready to go to work wherever you need it. Obviously, less installation cost is involved and less time is required to get the unit on stream.

Perfect balance is an exclusive Clark HMA feature achieved through a patented design principle. It is one of many important features that single out the Midget Angle as the only true field compressor built today. Over 650 installations prove its superiority.

If you have field gas to move, and you need compressors in the 85 to 440 bhp range, it will be to your advantage to contact the nearest Clark representative and write for Bulletin 126.

CLARK BROS. CO. • OLEAN, N. Y.
DIVISION OF DRESSER OPERATIONS, INC.
Sales Offices in Principal Cities throughout the World

Compact, factory packaged



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compressors

Clark sets the pace in compressor progress

*

EVERY TANK . . . EVERY TIME

WITH *Visco*

THE CONSISTENTLY EFFICIENT EMULSION BREAKER

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Call Houston, MADISON 0433, collect, for fast action on your emulsion-breaking problems.

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***Visco*®** DEHYDRATING AND DESALTING CHEMICALS • WHEREVER COST AND EFFICIENCY COUNT

watch lift COSTS GO DOWN

with GUIBERSON GAS LIFT EQUIPMENT

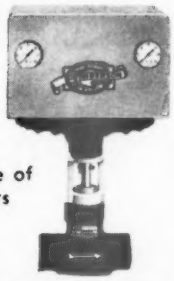
Guiberson's Complete Line of Gas Lift Equipment includes

Three types of Pressure Controlled Flow Valves

Type A

Check Valves—two types, spring loaded or velocity

Many types of mandrels, including Wrap-Around —Mashed In—Fluid Control



A full line of Controllers

Standard A

Type A Controller

Type C—Differential Pressure Flow Valves

. . . and a complete line of casing packers

When wells won't flow, operators in many fields are meeting rising oil production costs with gas lift. And more and more engineers and field men are finding that Guiberson equipment plus Guiberson experience is the way to the lowest gas lift cost with the greatest economy in initial installation.

Guiberson's line of equipment is complete, designed to solve almost every type of gas lift problem. Guiberson experience, derived from thousands of satisfactory installations, is your assurance that your well will give maximum production for a maximum length of time. No matter what your gas lift problem—intermitting or continuous flow; using lease gas or recycled gas, from single or dual producing zones—look to Guiberson for the equipment and experience that will cut your gas lift costs.

Write us for a recommended gas lift installation for your well.

Guiberson Gas Lift Equipment is protected by the following patents:
2,156,429 2,227,132 2,292,768 2,347,628 2,377,981
2,188,636 2,230,187 2,305,250 2,358,944 2,411,315
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GUIBERSON

CORPORATION

ESTABLISHED 1919 • DALLAS, TEXAS, U. S. A.

Sold By Leading Oil Field Supply Stores Everywhere

SANDFRAC AIDED BY MUD ACID

Effectiveness of Sandfrac increased by preliminary Mud Acid treatment to clean the formation face

Here's another case where Dowell ingenuity and know-how paid dividends on a well completed in a sandstone formation.

A breakdown of the formation with crude oil was attempted prior to a Sandfrac* treatment. Abnormally high injection pressures at low pumping rates indicated that the Sandfrac material could not be safely injected into the formation. Dowell engineers then decided to use Mud Acid to break down the formation and remove mud and other materials from the pay zone face.

As a result of this use of Mud Acid the Sandfrac injection pressure was reduced approximately 50 percent and the pumping rate was increased from 1 to 7 bbls/min.

The success of this and many other Dowell oilfield services is due largely to the versatility of the high-volume, heavy-duty equipment Dowell uses, and the interest of Dowell in helping to solve your problems. For all the facts call your nearest Dowell station, or write to DOWELL INCORPORATED, Tulsa 1, Oklahoma, Dept. H-15.

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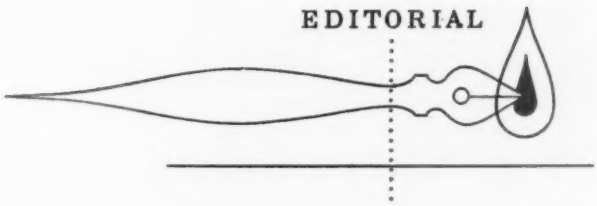
DOWELL SERVICE

chemical services for the oil industry

DOWELL

A SERVICE SUBSIDIARY OF THE DOW CHEMICAL COMPANY



WITH THANKS to OUR ADVERTISERS

T. C. FRICK*

VICE CHAIRMAN
PETROLEUM BRANCH, AIME

CHAIRMAN, PETROLEUM BRANCH
ADVERTISING ADVISORY COMMITTEE

This publication was founded in 1938 as a quarterly, 6 by 9 in. in size, named *Petroleum Technology*. Published by the New York Office of the Institute, the magazine was intended as a vehicle for distributing appropriate technical papers to the petroleum members of the Institute. This move was made in answer to the growing needs of the petroleum membership, which was about 12 per cent of the AIME at the time. It was also coincident with the establishment of an assistant secretary of the Institute to devote full time to the Petroleum Division, which position was ably filled for several years thereafter by Chester Naramore.

We are not familiar with the background of early advertising sales in the magazine, but an advertising sales program was a natural course because of the growing influence of the petroleum engineer in the industry. No advertising was published in 1938, but a few advertisers carried 15 pages in each of the years 1939 and 1940. In 1941, the publication was expanded to a bimonthly, and both the number of advertisers and the number of pages increased. During the war years both fluctuated, with no significant increase occurring until 1949, when the publication was changed to the present monthly JOURNAL OF PETROLEUM TECHNOLOGY, and the publication headquarters were brought to Dallas. The years since have brought a substantial increase as shown in Table 1.

By the end of 1954 we will have published a total of some 1,600 pages of advertising in the 16 years since the program was started. We believe our advertisers have received full value from their purchase of this space, for two reasons: (1) the influence of the petroleum engineer on the utilization of oil industry services and equipment has continually increased, and (2) the simple law of economics is that advertising must provide a business return in order to justify continuance. The growth in the number of our advertising pages seems to be prima facie evidence that the return was made.

Although our publication has given such value to our advertisers, the total *net income* to the Institute and Petroleum Branch over the 16 years for this advertising space is an estimated $250,000.00. By any standard, this is a substantial measure of assistance to the petroleum engineering profession. Net income to the Petroleum Branch from advertising in 1954 will be approximately $58,000.00, and the membership of the Branch, excluding students, on June 1 was 5,790. Hence, the advertising income for this year amounts to roughly $10.00 per member. We anticipate an average total income per member of about $32.00 for the year, of which advertising will be some 31 per cent. Some expense could be reduced if we did not publish advertising, such as the cost of printing color, but it is safe to say, generally, that our dues are now perhaps 25 per cent lower than they would be for essentially the same service if we did not publish advertising.

Thus, we are indebted to our many business friends who have provided this financial support. We express the thanks of the Petroleum Branch to them, and suggest to members that we can continue to merit this support only through their business patronage of our advertisers when the opportunity occurs.

Our current objective is to develop advertising to where the magazine will be self supporting. We believe the majority of our members are in accord with this objective, and that by observance of the ordinary tenets of cooperative business we can merit this financial support while providing a valuable advertising medium for the petroleum industry.

TABLE 1 – ADVERTISING GROWTH IN JOURNAL OF PETROLEUM TECHNOLOGY

Year	Number of Advertisers	Total Number of Advertising Pages in Year	Average Number Pages Per Advertiser
1938	0	0	0
1939	5	15	3
1940	4	15	3.7
1941	14	48	3.4
1942	14	52	3.7
1943	11	43	3.8
1944	11	46	4.2
1945	15	62	4.1
1946	15	61	4
1947	13	61	4.7
1948	13	66	5.1
1949	25	95	3.8
1950	27	98	3.6
1951	35	162	4.6
1952	61	232	3.8
1953	59	232	3.9
1954	65	300	4.6

★★★

*Manager, Production Division, The Atlantic Refining Co., Dallas

Pacific Technology Forum Report

DRILLING with NITROGEN and MICRO-HOLE DRILLING

Reported by
C. R. McEWEN
JUNIOR MEMBER AIME

UNION OIL CO. OF CALIFORNIA
BREA, CALIF.

Talks on two subjects were presented before the Pacific Petroleum Chapter at a recent meeting in the Engineer's Club, Biltmore Hotel, Los Angeles. Norman C. Wells, Long Beach consultant, discussed the use of nitrogen as a drilling fluid, and Richard J. Berryman, of Micro Drilling Co., described his company's midget drilling rig.

Drilling Oil Wells with Nitrogen

Data acquired during the completion of two wells in Signal Hill in 1938[1] using natural gas as a circulating medium was compared to estimates of what could be done today using nitrogen by the first speaker, Wells.

He pointed out that several improvements had been made over the techniques used in 1938. One important feature of the nitrogen, or so-called Grable system, is the removal of the fear of fire. Other improvements are the use of one special bit for penetrating the entire producing interval of 888 ft, the return circulation of gas through a small annulus in a double-concentric drill string which reduces the required circulation rate, and the use of the gas engine-driven gas compressors to effect a saving in fuel consumed over that required for the steam-driven compressors of 1938. Six days would be required for completion using the Grable system, whereas eight days were required for the 1938 wells, he stated.

The cost of nitrogen would be quite low as compared to liquid completion drilling fluids. With 8⅝-in. casing cemented in the shale above the zone at 3,842 ft and 888 ft of 7⅞-in. hole to drill in the zone, the cost of nitrogen to charge the system to 425 psi would be about $220. Assuming 100 per cent make-up every 24 hours, the total cost would be $1,320. This assumes a much higher pressure and rate of make-up than would actually be necessary.

Wells explained that four types of applications have been found for drilling with a gaseous medium:

1. Drilling, testing, and completing in a low pressure oil sand to obtain optimum production and depletion.

2. Drilling a fracture system to avoid plugging of the fractures penetrated.

3. Drilling porous gas sands to avoid contamination, lost circulation, and cleaning out for production.

4. Drilling for surface pipe where extreme conditions exist that are conducive to lost circulation.

In addition, it is envisioned that this type of drilling may be used for extreme running sand conditions that cannot be economically produced by other methods of completion, and for tight sands that are so badly impaired by conventional drilling fluids that they cannot be produced commercially. Also, output wells for repressuring or water-flooding operations designed to reduce by-passing of these wells might be drilled in this manner.

A number of disadvantages of liquid drilling fluids that can be overcome wholly or in part when drilling low pressure zones with a gas are:

(1) particle penetration, (2) chemical reaction of filtrates, (3) physico-chemical reaction of even slight amounts of water in filtrates by capillary intrusion, (4) mass chemical action conversion of calcium clays to sodium clays, (5) cavitation and caving due to velocity of fluid (liquid or gas) past the walls of the hole that has been made in the zone above the bit, (6) producing from only a part of the productive sand, (7) damage from partial or total lost circulation over and above the cost of the drilling fluid itself and, (8) in part at least, the tendency to by-pass output wells in any type of secondary recovery, including gas injection, water flooding, and in-situ combustion.

Elimination of these factors would reduce to zero the effect of drilling and completion time in the zone as applied to productivity of the well. In addition to this, uncontaminated cores and cuttings could be ob-

tained as well as true production tests at desired stages of drilling the zone wells stated.

Micro-Hole Drilling

Berryman's lecture dealt with the drilling of micro-holes, or "slim holes" as an exploratory tool. Slim-hole drilling has been in use in the mining industry nearly as long as rotary drilling has been practiced. Its application to the petroleum industry lies in the reduction of exploratory hole costs. This reduction is accomplished mainly through the use of smaller drill pipe and the smaller derrick capacity necessary to handle this pipe.

The micro-hole derrick has been designed to handle 6,000 ft of drill pipe, which is 1¼-in. upset tubing, the hole being about 2¾-in. in diameter. A special bit has been developed for this purpose. To date 20,000 ft have been drilled by the Micro Drilling Co., with an average bit life of 240 ft and an average penetration rate of 14 ft/hour.

Further reduction in fixed drilling costs are effected by the small area necessary for the drilling site, 28 ft by 60 ft. The small hole size results in a small fluid system, approximately 9 bbls/1,000 ft, which should cost about one-tenth as much for mud and chemicals as in drilling a conventional 10⅝-in. hole. A two-man crew can lay down and make up this light-weight drill pipe to depths of 3,000 to 4,000 ft.

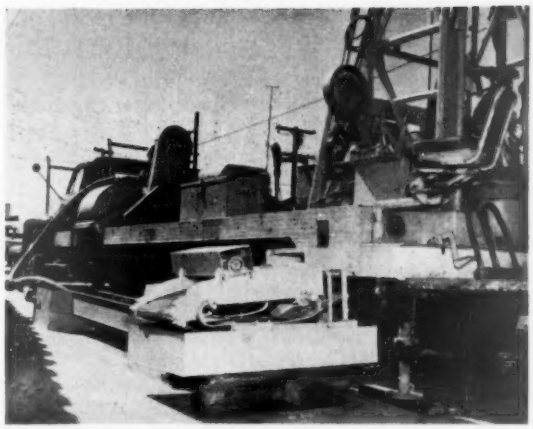
The use of the small diameter hole at present precludes the use of a number of down-hole tools, such as dip meters, side-wall samples, and neutron and gamma ray logs. However, electric logs, oriented punch cores, directional surveys, and conventional cores have all been taken in the micro-hole.

To date the micro-hole has been used for:

(1) checking shallow seismic plays, (2) checking the productive limits of known oil structures, (3) locating and testing of fresh water strata for water wells, and (4) wildcats.

Some of the suggested uses for the micro-hole are:

1. Checking stratigraphic geology of a deep objective.
2. Checking underlying geology of alluvium fills to complete geological mapping.



Micro-Hole Drilling Rig

3. Completing shallow wells with 1¼-in. plain tubing as gas wells or waste water disposal wells.

From the cost data gathered thus far it has been possible to estimate the cost to an operator of drilling a 3,000-ft hole. The cost per foot of hole would be $2.17, assuming a move of 100 miles each way, an estimated time for rigging up and dismantling, drilling the surface hole, running and cementing 200 ft of surface pipe, drilling at the rate of 14 ft/hour with an average bit life of 235 ft, and time for logging and abandoning hole. Total time required would be 13 days and 17 hours. The cost of bits, surface casing cement, logging services, survey rentals, mud and chemicals, and location cost, would add another $0.57/ft, for a total of $2.74/ft of hole drilled and abandoned.

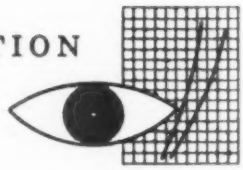
Berryman feels that the micro-hole has a place in the industry as an exploratory tool today, and that considerable improvement can be expected. At present it is probably necessary to compromise on size for holes deeper than about 4,000 ft to, say, 4-in. diameter. However, industry will dictate the solutions to present problems, as the micro-hole is increasingly employed.

Reference

1. Wells, N. C.: *World Oil* (November, 1952), 135, No. 6, 139.

★★★

REPORT and INTERPRETATION



JOE B. ALFORD

EXECUTIVE SECRETARY
PETROLEUM BRANCH, AIME

Petroleum Branch Fall Meeting

In mid-July, the Housing Committee had received reservations for about 2,050 persons for the Fall Meeting in San Antonio, October 17-20. We do not have figures to compare this with the reservations at the same time last year, but it is considerably larger, as this figure is within a hundred or so of the total attendance at the 1953 meeting. So, this seems to indicate that we are going to have a crowd. We are anticipating about 2,200 men and 400 ladies, but will be prepared to handle a total attendance of 3,000.

Although the primary hotels in San Antonio are booked to capacity at this point, there are still some rooms available in the smaller hotels, as well as a sizeable block of rooms in motels north of the city. If you are going to the meeting but have not yet arranged reservations, it should be done without delay. Write direct to: Housing Committee, Petroleum Branch AIME Fall Meeting, 150 Transit Tower, San Antonio.

Technical Program

The program for the meeting, showing the titles and authors of papers, is shown on pages 45 and 46 of the July issue. A few other papers have been added to those listed, making a total of 49 now on the program. Three concurrent technical sessions will be held each morning on Monday, Tuesday, and Wednesday, and two concurrent technical sessions during the afternoon of each day. The program promises to be a good one, as it has "a little something for everybody," and a number of important contributions are contained in the papers.

Registration and Exhibits

An advance registration will be conducted again this year, with appropriate forms to be mailed to the membership sometime in September. Registration will be $5.00 whether executed in advance or at the meeting. The advance registration will give members and their ladies first choice at tickets to the social functions, which is an advantage to members as some of the social functions will have a definite limit on attendance.

Luncheons

The Petroleum Branch Welcoming Luncheon will be held for the men in attendance at noon on Monday, in the Roof Garden and adjacent rooms of the Plaza Hotel. A prominent individual has been invited as speaker. A new Petroleum Branch medal for professional achievement in petroleum engineering has just been established as a memorial to Cedric K. Ferguson, and it will be presented for the first time at the Welcoming Luncheon.

For the first time this year, the Branch will stage a Membership Luncheon, at noon on Tuesday in the Ballroom of the Gunter Hotel. The purpose of the luncheon will be to get members together on an informal basis to hear a brief report on current affairs of the Branch by the Branch Chairman. Non-members will also be invited, and it is anticipated now that two door prizes will be given for attendance: a good set of golf clubs and a good shotgun. Two guys will be lucky and happy for attending the luncheon, aside from the enjoyment of the occasion itself. Better plan to go!

Evening Social Functions

On Monday evening, October 18, the Branch will hold a Barbecue Supper and Frontier Party at MacArthur park in north San Antonio. After the supper open air dancing will be held at two nearby floors in the park. There will be tables available for seating during the supper, with roaming troubadours for entertainment. Dress for the occasion is very informal — blue jeans, and calico shirts, or other frontier regailia is recommended.

On Tuesday night, October 19, the Petroleum Branch Banquet and Dance will be held at Club Seven Oaks, an extensive country club facility, on the Austin highway. Negotiations for a good name band are now under way, and the evening promises to uphold the standard of the same party held there in October, 1949, which many members recall as one of the best we have ever had.

Ladies' Activities

With the help of several ladies on her committee, Mrs. R. K. Guthrie, Jr. of San Antonio, has arranged two outstanding affairs for the ladies. First is a Welcoming Merienda, to be held in the patio of Witte Museum in San Antonio's famed Brackenridge Park on Monday, from 10:30 to 12:30. A Latin-American theme will be carried out in the decorations and food for the occasion, and the ladies will be entertained in a number of ways.

A luncheon and style show will be held in the Menger Hotel on Tuesday, October 19, staged by one of the prominent San Antonio stores. In addition to these, the ladies will attend the parties on Monday and Tuesday evenings, and will be invited to view a colored photographic slide presentation on Wednesday a.m. entitled "How Petroleum Engineering Increases Oil Recovery." This has recently been developed by the Petroleum Branch staff, and will be presented especially for the ladies attending the Meeting.

General

Although the attendance at the Branch Fall Meetings has increased over 200 per cent within the past four years, and the scope of the meetings expanded likewise, there appears to be much more growth ahead. We think this is desirable, for the profession will thrive so long as we continue to hold good our meetings. ★★★

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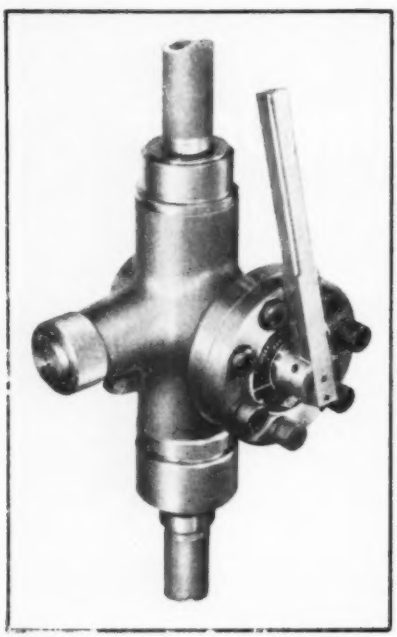
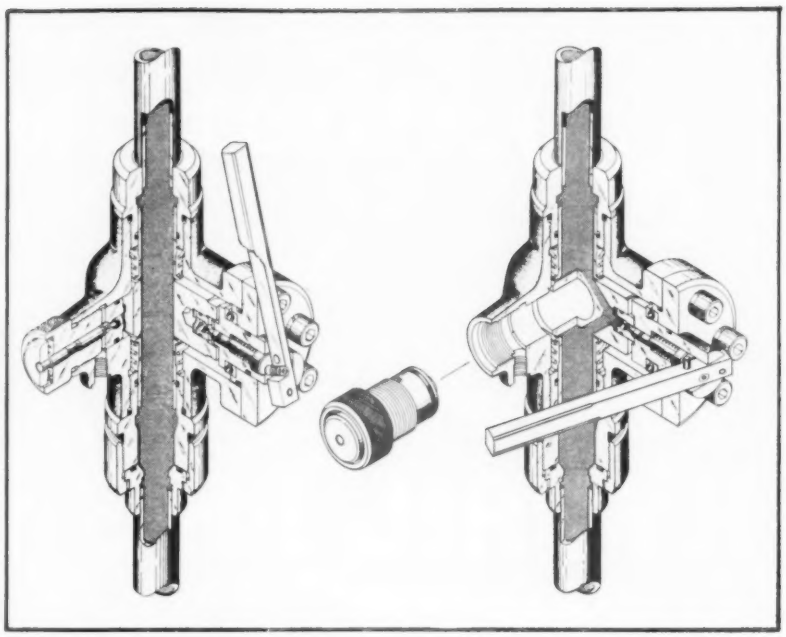


(1) Photograph of new soluble plug injector with handle in operating position.



(2) Section drawing through soluble plug injector showing flow in "operate" position.

(3) Flow through injector when handle is in "load" position. Loading cap removed.

Unique high pressure valve permits operator to

Inject Paraffin Control Plugs Without Flow Interruption

A new valve, which has recently been perfected, permits the insertion of soluble plugs into high pressure oil lines without interrupting flow.

Where It Is Used—The principle use of the new device, called a "soluble plug injector," will be as a part of the hydraulic system of pumping oil wells. In that system, deposition of paraffin in surface lines and in well tubing is removed by using hydraulic power to force soluble plugs through the line to scrape paraffin loose. It is normal practice to force the paraffin either to the bottom of the well in the case of tubing deposits, or to the tank in the case of surface flow lines.

To perform the operation of injecting soluble plugs it has heretofore been necessary to shut off flow and drain the line prior to inserting the plug. The new injector, however, eliminates this requirement and thereby greatly simplifies the operation.

In its present form, the new injector is applicable for injecting plugs in surface power oil lines at the central power control station. It is also used under the 4-way valve of the parallel type hydraulic Free Pump System for running soluble plugs down the production (small string) tubing.

The injector is available in 1″ and 1¼″ sizes and is designed for 5,000 psi working pressure.

How It Works—The assembly is of unique design. Within its cast steel body is a plug which is square in cross section. Through this square plug is a large diameter hole which serves as the loading chamber for the soluble plug. In the operating position, the square plug is oriented so the large hole is in line with the flow going through the injector. The square plug itself is held between two spring loaded shoes which serve to direct flow through the hole.

When the square plug is turned 90° (to "Load" position) by the external operating handle, the spring loaded shoes unseat as the plug is rotated. They ride up over the corners of the plug, and slide to a new seat on a pair of opposing faces. In this position, there is a fluid channel between the two shoes through a hole drilled in the square plug so as to bypass the loading chamber.

In the load position, the chamber in the square plug is in line with a loading cap. By bumping a bleeder valve in the cap, the line pressure within the loading chamber is relieved and the cap can be removed.

At this time, the seating shoes are hydraulically held on seat and force the line fluid to flow through the bypass channel. As soon as the soluble plug is inserted in the loading chamber and the cap replaced, the operating handle is turned back to "Operate" position. This puts the soluble plug into the flow stream which forces it down the line. Flow through the injector is continuous throughout the operation—it is never interrupted.

Availability—The soluble plug injectors are available, in any quantity. Order from the manufacturer, **KOBE, INC.,** 3040 East Slauson Avenue, Huntington Park, California, or through any of the company's district offices.

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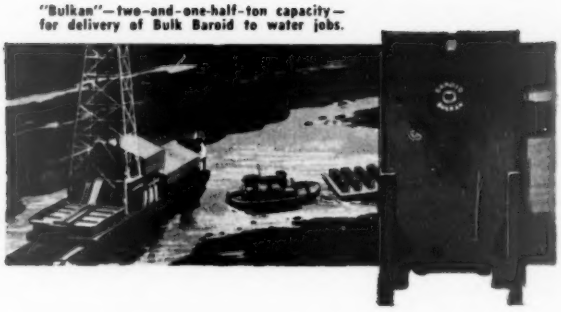

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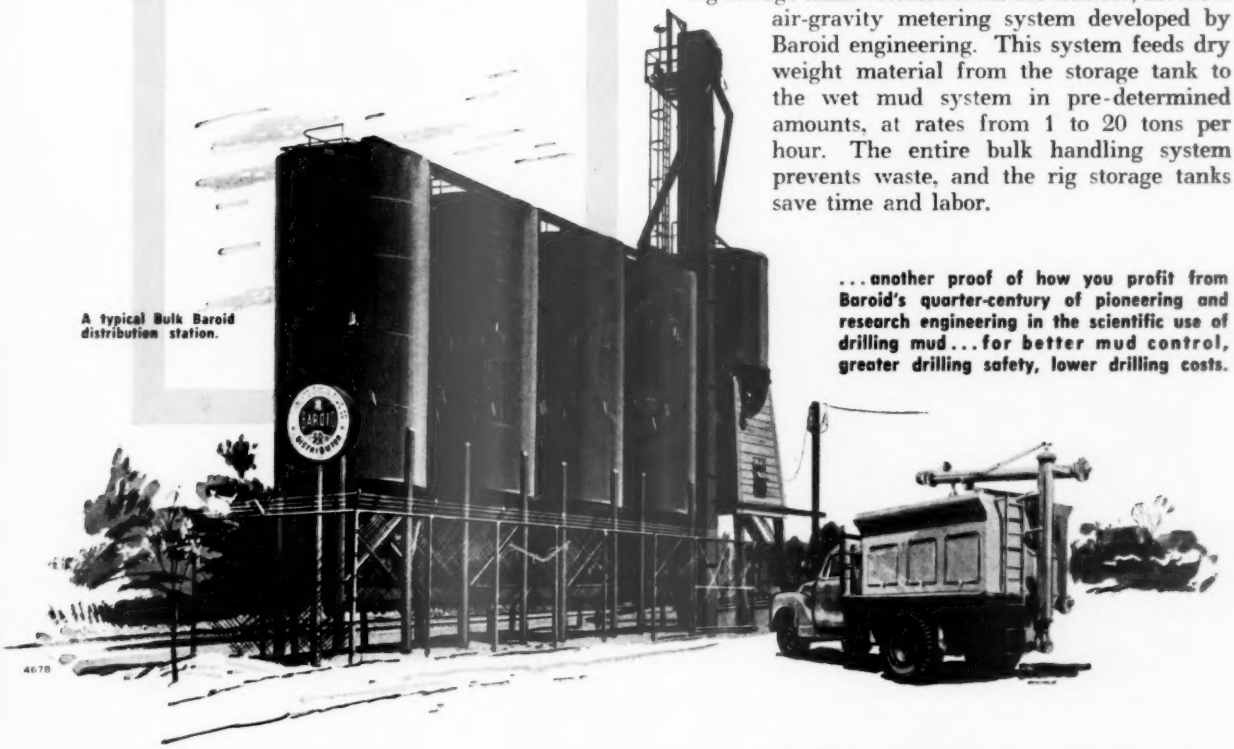
A typical Bulk Baroid distribution station.



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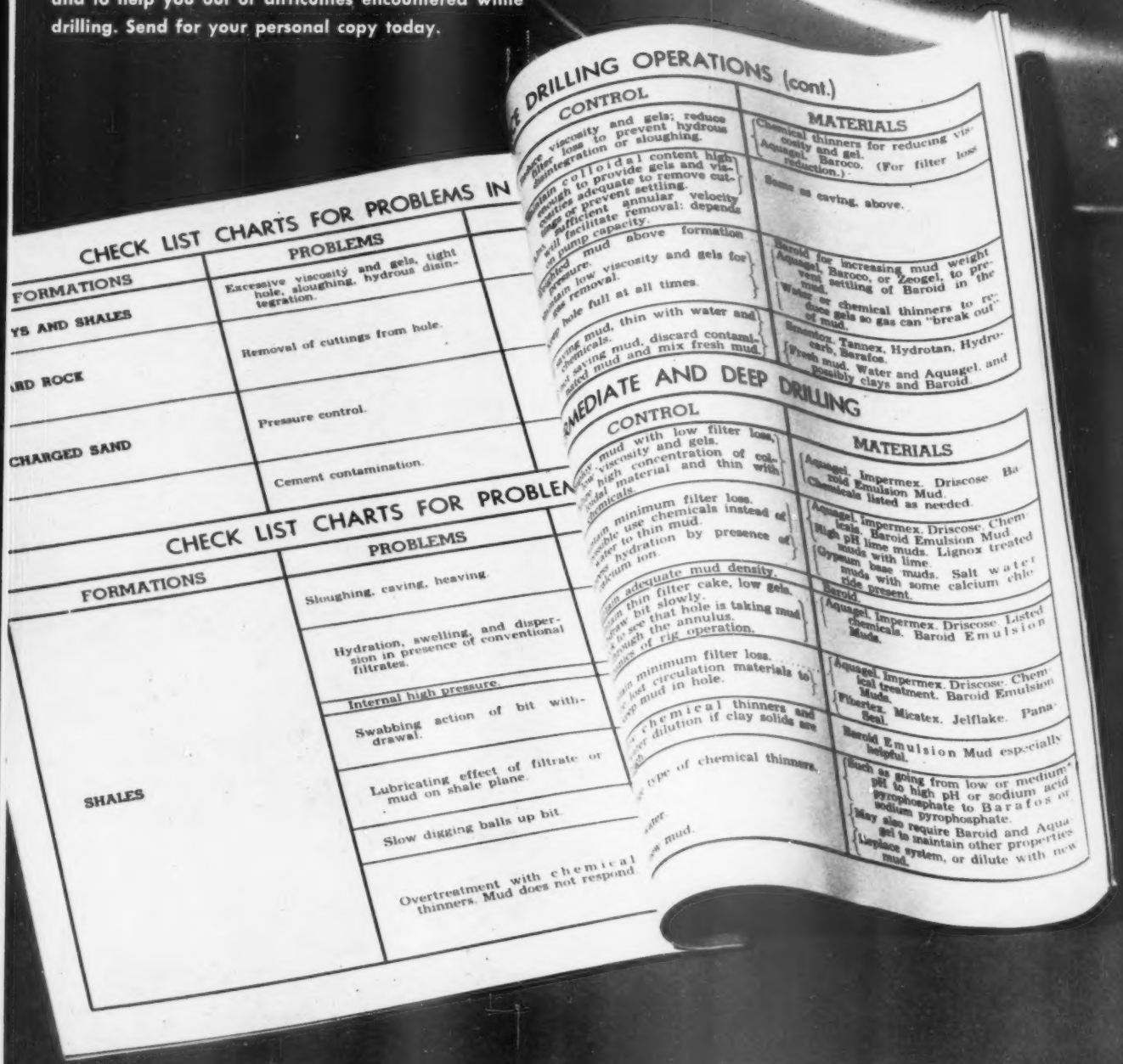

CHECK LIST CHARTS FOR PROBLEMS IN

FORMATIONS	PROBLEMS
YS AND SHALES	Excessive viscosity and gels, tight hole, sloughing, hydrous disintegration.
ARD ROCK	Removal of cuttings from hole.
CHARGED SAND	Pressure control.
	Cement contamination.

CHECK LIST CHARTS FOR PROBLEA

FORMATIONS	PROBLEMS
SHALES	Sloughing, caving, heaving.
	Hydration, swelling, and dispersion in presence of conventional filtrates.
	Internal high pressure.
	Swabbing action of bit withdrawal.
	Lubricating effect of filtrate or mud on shale plane.
	Slow digging balls up bit.
	Overtreatment with chemical thinners. Mud does not respond.

F DRILLING OPERATIONS (cont.)

CONTROL	MATERIALS
...duce viscosity and gels; reduce filter loss to prevent hydrous disintegration or sloughing.	Chemical thinners for reducing viscosity and gel. Aquagel, Baroco. (For filter loss reduction.)
...tain colloidal content high enough to provide gels and viscosities adequate to remove cuttings or prevent settling. ...sufficient annular velocity ...ill facilitate removal: depends ...n pump capacity.	Same as caving, above.
...ghting mud above formation ...pressure. ...ain low viscosity and gels for ...gas removal.	Baroid for increasing mud weight. Aquagel, Baroco, or Zeogel, to prevent settling of Baroid in the mud.
...p hole full at all times.	Water or chemical thinners to reduce gels so gas can "break out" of mud.
...ving mud, thin with water and ...chemicals. ...ng mud, discard contaminated mud and mix fresh mud.	Bentonite, Tannex, Hydrotan, Hydrocarb, Barafos. Fresh mud. Water and Aquagel, and possibly clays and Baroid.

MEDIATE AND DEEP DRILLING

CONTROL	MATERIALS
...y mud with low filter loss, ...w viscosity and gels. ...w high concentration of colloidal material and thin with ...chemicals.	Aquagel, Impermex, Driscose, Baroid Emulsion Mud. Chemicals listed as needed.
...ain minimum filter loss. ...ssible use chemicals instead of ...ater to thin mud. ...ase hydration by presence of ...alcium ion.	Aquagel, Impermex, Driscose, Chemicals, Baroid Emulsion Mud. High pH lime muds. Lignox treated muds with lime. Gypsum base muds. Salt water muds with some calcium chloride present.
...ain adequate mud density. ...ain thin filter cake, low gels. ...raw bit slowly. ...k to see that hole is taking mud ...rough the annulus. ...ues of rig operation.	Barold. Aquagel, Impermex, Driscose. Listed chemicals. Baroid Emulsion Muds.
...ain minimum filter loss. ...e lost circulation materials to ...p mud in hole.	Aquagel, Impermex, Driscose. Chemical treatment. Baroid Emulsion Muds. Fibertex, Micatex, Jelflake, Panaseal.
...e chemical thinners and ...ter dilution if clay solids are ...h.	Baroid Emulsion Mud especially helpful.
...e type of chemical thinners.	Such as going from low or medium pH to high pH or sodium acid pyrophosphate to Barafos or sodium pyrophosphate. May also require Baroid and Aquagel to maintain other properties. Lignox system, or dilute with new mud.
...ater. ...ne mud.	

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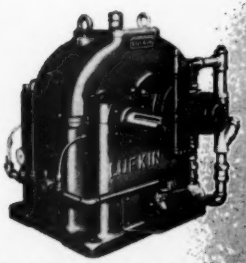

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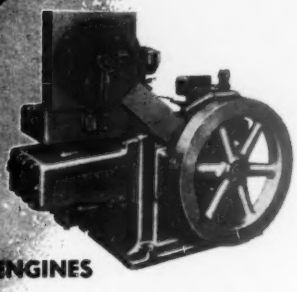

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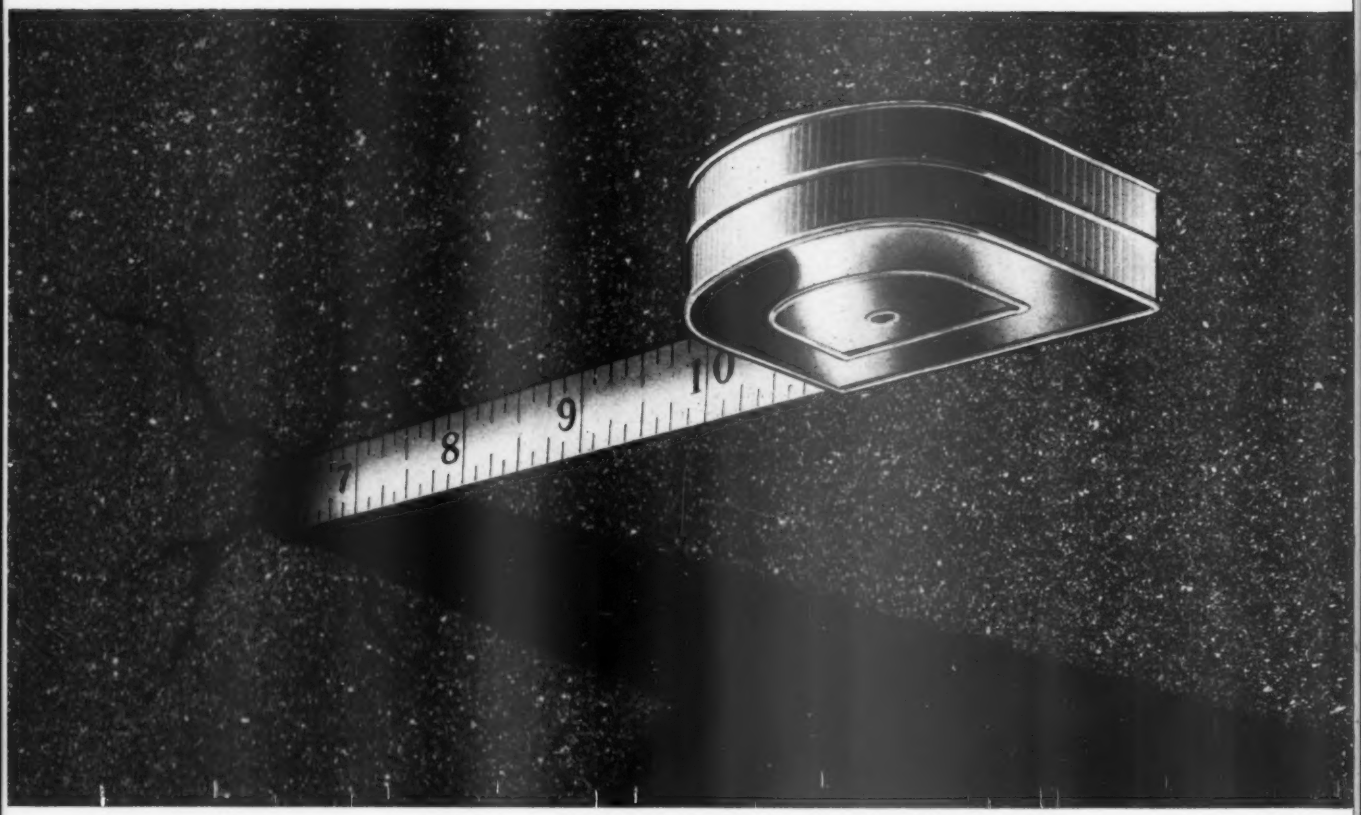

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PETROLEUM TRANSACTIONS

RESERVOIR FRACTURING — A METHOD of OIL RECOVERY from EXTREMELY LOW PERMEABILITY FORMATIONS

L. E. WILSEY
ASSOCIATE MEMBER AIME
W. G. BEARDEN
JUNIOR MEMBER AIME

STANOLIND OIL AND GAS CO.
TULSA, OKLA.

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ABSTRACT

This paper presents results of analysis of the effect of fracturing on initial flow rates and on ultimate recoveries from low capacity oil formations. This analysis shows that even in formations of permeability as low as 0.1 md, large fracture treatments can yield oil recoveries and production rates approaching those of high permeability formations. Field production information is shown which supports the analytical work.

INTRODUCTION

Often hydrocarbon bearing formations are discovered which, while they are known to contain large quantities of oil, will not produce at commercially attractive rates without special well stimulation. Attempts to solve this problem led to the development of such techniques as underreaming, shooting, acidizing, and recently hydraulic fracturing. These methods of stimulation have been highly successful in many fields. All of these treatments, however, affect only the pay section near the well bore and therefore owe their success to circumventing and overcoming local permeability reduction about the well bore.

It has been the belief that in treating wells to stimulate production in which there is no permeability reduction near the well, the maximum possible production rate increase would be of the order of two or fourfold. Hence, it has been concluded that fracture treatment of uniformly low capacity (permeability times thickness) formations could meet with but limited success.

It is the purpose of this paper to show that the use of fracture treatments much larger than usually used can yield commercially attractive producing rates and high recoveries even in formations of permeability less than 0.1 of a md.

PROCEDURE

In order to illustrate the effects of fracturing, an analytical study of some hypothetical systems was made in which one factor at a time was varied to show what is important in recovering oil from fractured wells. It was assumed that a horizontal fracture of relatively high fluid-carrying capacity extended from a well bore. The presence of such a fracture will cause a marked influence on the flow pattern and pressure distribution in the formations, with the net effect being to reduce tremendously the resistance to flow into the well bore.

A diagram of the resulting flow pattern and pressure distribution is illustrated in Fig. 1. Immediately after production commences, the principal flow of fluid is vertically from the formation flanking the fracture, into the fracture, and then into the well. After sufficient oil and gas have been produced to lower the pressure in the formation adjacent the fracture, oil and gas will begin to flow in a radial manner into the fracture from the formations beyond the end of the fracture.

In calculating the performance under such conditions, the material balance or conservation of matter equation and equations of flow were solved simultaneously by a stepwise method of calculation. Flow rates were found by determining the pressure distribution, as illustrated

Manuscript received in the Petroleum Branch office Sept. 24, 1953.
Paper presented at the Petroleum Branch Fall Meeting in Dallas, Oct. 19-21, 1953.
Discussion of this and all following technical papers is invited. Discussion in writing (3 copies) may be sent to the offices of the Journal of Petroleum Technology. Any discussion offered after Dec. 31, 1954, should be in the form of a new paper.

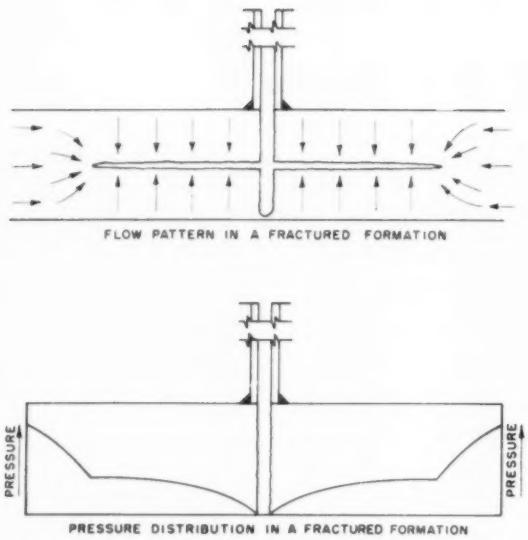

FIG. 1 — EFFECT OF FRACTURING ON FLOW PATTERNS AND PRESSURE DISTRIBUTIONS.

in Fig. 1, at each average reservoir pressure. Linear flow into the fracture from the formation was found by using volumetrically weighted average pressure of the reservoir rock flanking the fracture; radial flow into the fracture was found from the pressure at the extremity of the fracture and at the limit of the drainage area.

From these calculations the flow rates and time to reach a particular stage of depletion could be determined. The ultimate recovery was found by calculating the pressure when the flow rate had declined to the assumed abandonment rate. The recovery factor was fixed as the sum of the oil produced from the formation methods would likely have very little if any water yond the end of the fracture divided by the total oil in place in the assumed drainage area of the well.

In this study only volumetric or depletion drive reservoirs were considered since a reservoir too tight to produce satisfactorily without special well stimulation methods would likely have very little if any water influx. No attempt was made to stimulate any particular well or reservoir, but instead, arbitrary values of oil in place per foot of thickness, abandonment, producing rate, producing bottom hole pressure, crude characteristics, etc., were chosen. These arbitrary characteristics are listed in the Appendix.

RESULTS AND DISCUSSION

The recovery of oil from a fractured well is affected by the characteristics of the formation and the fracture in a rather complex manner in that the same recovery can result from several different combinations of rock and fracture characteristics. Therefore, in order to show the effect on recovery, each factor is discussed separately.

EFFECT OF FORMATION PERMEABILITY ON ULTIMATE RECOVERY

As this study was directed toward recoveries from extremely low permeability formations, the first factor investigated was the effect of permeability on the ultimate recovery from a fractured well. The results of this analysis are shown on Fig. 2 which is a plot of recovery factor versus permeability. The "maximum recovery" indicated on this and subsequent figures is the recovery which would result if the well were produced to an abandonment rate of 10 BOPD with a 100 psi well bore pressure. This "maximum recovery" is a theoretical recovery which serves as a reference to show how nearly complete is the recovery from a particular part of the reservoir.

The results of this analysis show that recovery continually decreases as the permeability decreases. Fig. 2, however, shows that with a 625-ft fracture, this decrease in recovery is not as large as might be expected, particularly from the formations flanking the fracture. The range of permeability used in preparing this figure may at first seem unusually low since it has been the general practice of geologists and engineers to neglect very low permeabilities and not even measure them below about 0.1 to 0.05 md. However, formations of permeability below this are known to exist and do contain oil which can be recovered by proper fracture treatment. Even for permeabilities of the order of .001 of a md, very high recoveries are obtained from the formations flanking the fracture; hence, if a large proportion of the oil in place is in the formation flanking the fracture, the permeability below which recovery is negligible is extremely low.

The high recoveries in very low permeability formations shown on Fig. 2 result from changing the flow pattern in much of the drainage area. Instead of requiring all of the fluids to converge on the well through the low permeability formations, much of the fluid flows only a short distance vertically in the tight

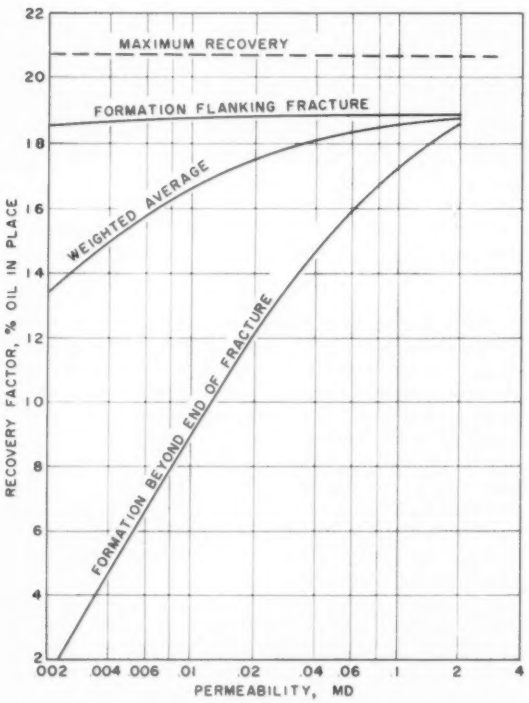

FIG. 2 — EFFECT OF FORMATION PERMEABILITY ON ULTIMATE RECOVERY.

Formation thickness = 30 ft. Fracture carrying capacity = 30 md-ft. Radius of fracture = 625 ft. Abandonment rate = 10 BOPD. Well bore pressure at abandonment = 100 psi. Normal relative permeability and crude characteristics as indicated in Appendix.

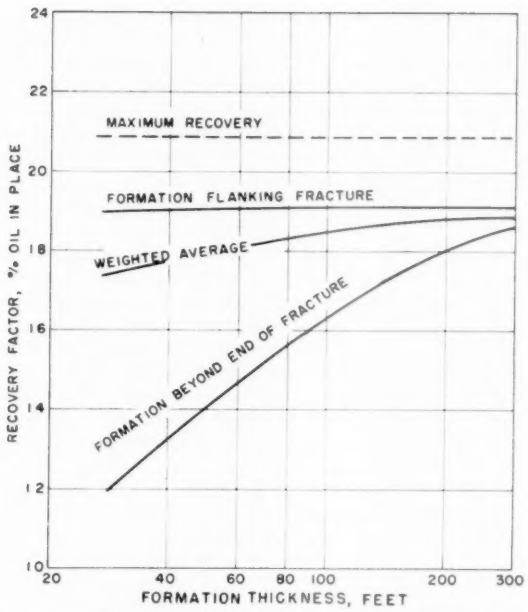

FIG. 3 — EFFECT OF FORMATION THICKNESS ON ULTIMATE RECOVERY.

Formation permeability = .02 md. Fracture carrying capacity = 30 md-ft. Radius of fracture = 625 ft. Abandonment rate = 10 BOPD. Well bore pressure at abandonment = 100 psi. Normal relative permeability and crude characteristics as indicated in Appendix.

formation to a high capacity or low resistance avenue to the well.

EFFECT OF FORMATION THICKNESS ON ULTIMATE RECOVERY

Fig. 3 presents the results of an analysis of the effect of formation thickness on ultimate recovery. This figure shows that the recovery both from the formations flanking the fracture and from the zone of radial flow beyond the end of the fracture increases as the thickness of the formation increases. This is due to the decrease in the per foot abandonment producing rate with increasing formation thickness. For example, if the abandonment producing rate is 10 BOPD, a well drilled in a 10-ft formation will result in some recovery which is dependent on fluid and formation characteristics. If the abandonment producing rate for this well could be reduced to 1 BOPD, other factors being equal, a higher recovery would result.

A well completed in a 100-ft formation with a 10 BOPD abandonment rate is equivalent to 10 wells with 1 BOPD abandonment rates, each producing from 10-ft formations but producing through a common well bore. Actually, Fig. 3 indicates that even though the recovery from the formation flanking the fracture increases with thickness, this increase is of very small magnitude. This means that in very low permeability formations, essentially complete recovery of the oil contained in the rocks flanking the fracture is obtained at all reasonable formation thicknesses.

Throughout this paper an abandonment rate of 10 BOPD is used. This abandonment rate is arbitrary, but lowering it merely serves to make the difference between the recovery from the formation beyond the end of the fracture, the formation flanking the fracture, and the "maximum recovery" less. Conversely raising the abandonment rate would serve to increase these differences.

EFFECT OF FRACTURE CHARACTERISTICS ON ULTIMATE RECOVERY

To determine the effect of fracture characteristics on ultimate recovery, calculations of the recovery were made when the producing rate had declined to an assumed abandonment rate of 10 BOPD. Cumulative production expressed as a percent of the oil in place was then plotted against the assumed radius of fracture. Fig. 4 of this paper presents the results of this analysis for three different values of the fracture flow capacity.

Fig. 4 shows that for any given carrying capacity of the fracture, the recovery increases rapidly with increases in radius of the fracture. Moreover, when the fracture radius approaches the well spacing, the recovery approaches the maximum possible in a volumetric reservoir. This follows from the fact that most of the total pressure drop occurs beyond the end of the fracture; therefore, at the time of abandonment, all the reservoir rock flanking the fracture is substantially at the well bore pressure. Hence, as more of the total reservoir flanks the fracture, the higher will be the recovery.

Fig. 5 is a cross plot of the data presented in Fig. 4 with the recovery factor plotted against the fracture flow capacity for three different fracture radii. Fig. 5 illustrates that when the fluid-carrying capacity of the fracture is of low magnitude, say 30 md-ft, the recovery for any given radius of fracture increases rapidly with small increases in fracture capacity. However, when the fracture-carrying capacity is high (in the order of 200 md-ft), large increases in fracture capacity result in only small increases in recovery. This is due to the decrease of the fraction of the total pressure drop occurring in the fracture with increases in fracture capacity. This, in turn, causes less change in recovery.

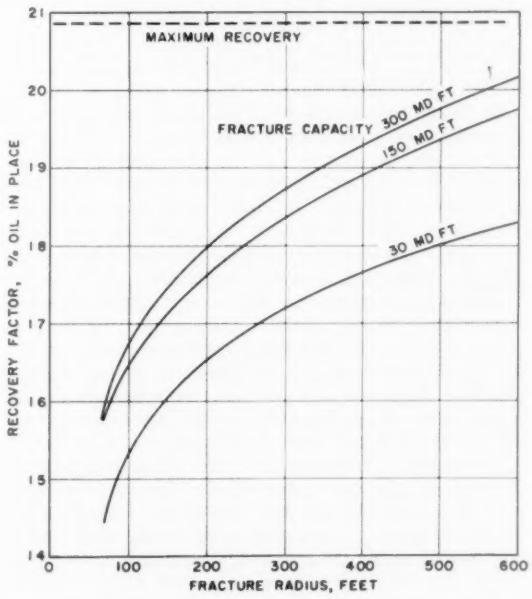

FIG. 4 — EFFECT OF FRACTURE CHARACTERISTICS ON ULTIMATE RECOVERY.

Formation permeability = 0.2 md. Abandonment rate = 10 BOPD. Well bore pressure at abandonment = 100 psi. Normal relative permeability and crude characteristics as indicated in Appendix.

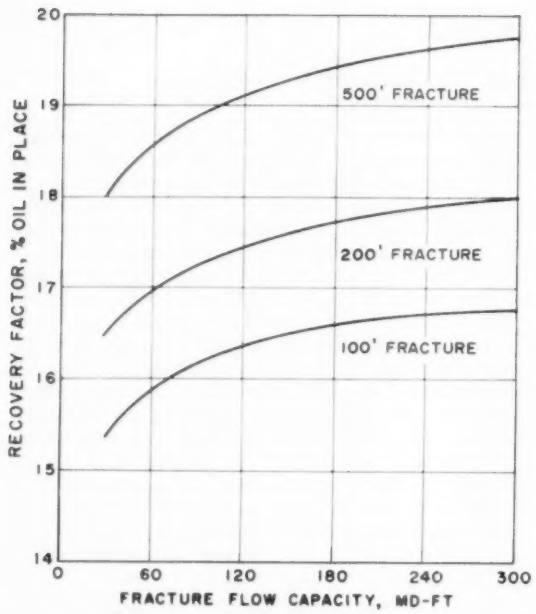

FIG. 5 — EFFECT OF FRACTURE FLOW CAPACITY ON ULTIMATE RECOVERY.

Formation permeability = 0.2 md. Abandonment rate = 10 BOPD. Well bore pressure at abandonment = 100 psi. Normal relative permeability and crude characteristics as shown in Appendix.

Undoubtedly, many factors influence the values of the fracture flow capacity; the formation itself to a large part determines the capacity. In general, laboratory tests indicate that increases in propping agent size and concentration will result in increased flow capacity. The magnitude of the fracture flow capacity was found to vary from 10 md-ft to several thousand md-ft, depending on well conditions.

EFFECT OF FRACTURE CHARACTERISTICS ON INITIAL POTENTIAL

The preceding results have indicated that formations of permeability considerably below what is considered commercially productive can produce substantial quantities of oil if a long radius fracture is made. In order that it be economically feasible to recover this oil, relatively high initial producing rates must be obtainable since, in addition to the normal drilling costs, a considerable expense is incurred in creating a long radius of fracture. Therefore, the effects of fractures on initial producing rates were studied.

The effect of fracture characteristics on initial potential is illustrated on Fig. 6 which is a plot of productivity index versus cumulative recovery plotted on a logarithmic scale. Illustrated on this plot are nine conditions which might result from fracturing a formation.

This figure illustrates that the initial potential or productivity index of a well is not sufficient to evaluate a deeply penetrating fracture treatment. If the capacity of the fracture is large compared to the capacity of the formation, the initial potential of a well is a measure of the fracture flow capacity and very little else. This may be observed by comparing the initial potentials resulting from a 150 md-ft fracture capacity with those resulting from a 30 md-ft fracture capacity. From Fig. 6 it may be seen that if the fracture capacity is 150 md-ft, the initial productivity index is approximately 0.27 regardless of the fracture radius; if, on the other hand, the fracture capacity is 30 md-ft, the initial productivity index is only 0.06 which again is not influenced by the fracture radius. The second purpose of Fig. 6 is to illustrate that the length of time a well can maintain a high initial productivity is directly related to the length of the fracture, i.e., the longer the fracture, the longer the period of high productivity.

RADIUS OF FRACTURE REQUIRED

Figs. 2 to 6 have shown that the low recoveries in very low permeability formations are caused by the radial nature of flow into wells which can largely be overcome by making a deeply penetrating fracture to reduce the flow in the formation to essentially linear flow. Under these conditions of linear flow, high recoveries can be obtained despite low matrix permeability as the pressure in the formation flanking the fracture may be reduced to a low value at reasonably high producing rates.

Figs. 2 and 6 have also shown, however, that as the permeability or capacity of the formation increases, the increase in ultimate recovery from fracturing uniformly permeable formations becomes smaller. Uniformly permeable formations of high capacity allow the average reservoir pressure to be reduced to a low value at commercial producing rates without the aid of fracturing.

From the above discussion, it may be seen that the radius of fracture required to obtain high recoveries in formations of uniform permeability is dependent upon the formation capacity. If the formation capacity is extremely low, substantial recovery can only be obtained from that portion of the formation flanking the reservoir fracture. Therefore, for all practical purposes, recovery from low capacity formations is directly influenced by the areal extent of the fracture.

Well spacing influences the radius of fracture required only to the extent that the same fraction of the reservoir

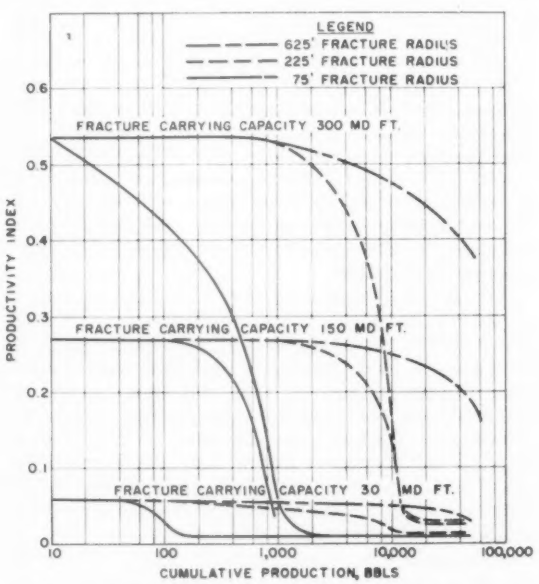

FIG. 6 — INFLUENCE OF FRACTURE CHARACTERISTICS ON INITIAL POTENTIAL.

Formation thickness = 30 ft. Formation permeability = 0.2 md. Oil in place = 400 bbls/acre-ft. Normal relative permeability and crude characteristics as indicated in Appendix.

rock can be flanked by several shorter fractures extending from closely spaced wells instead of by one long fracture from a well on wider spacing. If, for example, a certain recovery can be obtained from one well on 40-acre spacing which contains a fracture of 196,000 sq ft areal extent (fracture radius = 500 ft), the same recovery for the 40 acres under consideration may be obtained from four wells, each well containing a fracture of 196,000/4 or 49,000 sq ft areal extent. In the latter instance, the radius of fracture required in each of the four wells to result in the same recovery from the 40-acre block is only 250 ft.

The relationship between formation fluid capacity, well spacing, and radius of fracture is illustrated on Fig. 7 which is a plot of formation capacity versus recovery to an assumed abandonment producing rate of 10 BOPD. From this figure, it may be observed that as the formation capacity decreases, the radius of fracture required to attain the same recovery increases.

For example, if the formation capacity is 60 md-ft, wells on 40-acre spacing with no fractures yield a recovery of 19 per cent; if the formation capacity is 40 md-ft, 75-ft fractures on 40-acre spacing, or 37-ft fractures in wells on 10-acre spacing, are required to yield a recovery of 19 per cent. Similarly, if the formation capacity is only 6 md-ft, 625-ft fractures on 40-acre spacing, or 312-ft fractures on 10-acre spacing, are required to result in a 19 per cent recovery.

Thus, in general, the radius of fracture required to obtain a given recovery in a uniform permeability formation is dependent upon the formation capacity and the well spacing; the lower the capacity, the longer the fracture and the closer the well spacing, the shorter the fracture.

In applying the information from Fig. 7, allowance must be made for differences between the reservoir where it is being applied and the system assumed in this study. If a more viscous crude is encountered than the one used in this study, the beneficial effects of making a large fracture will continue at higher capacities, kh, than indicated in this figure. For example, the same increase in recovery by making a 225-ft fracture, as is shown on Fig. 7 for a 10 md-ft capacity formation, would occur in a 100 md-ft formation if the reservoir contained a crude with a viscosity of 10 cp instead of about 1 cp viscosity as is used in this study.

Similarly, but to a lesser degree, the gas in solution, the reservoir volume factor of the crude oil, and the relative permeability characteristics of the formation also tend to change formation capacity where the highly beneficial effects of deeply penetrating fractures begin. Thus, Fig. 7 must be used as a qualitative guide in selecting reservoirs for large volume, deeply penetrating fracture treatments rather than an inflexible yardstick.

When considering large fracture treatments, allowance must also be made for precipitation of solids or semisolids from the produced fluids. Little is known about the exact causes of this precipitation; however, often waters are produced which contain dissolved salts which may precipitate as a result of lowering the pressure in the vicinity of the well. Also, in formations of low permeability, some crudes have a tendency to plug the rocks. If the plugging resulting from reducing pressure occurs throughout the reservoir, the effect will be the same as discussed in regard to recovery of highly viscous oil; namely, plugging of the formations throughout tends to increase the capacity, kh, where deeply penetrating fractures are needed. If lack of ability of a well to produce is the result of local precipitation or

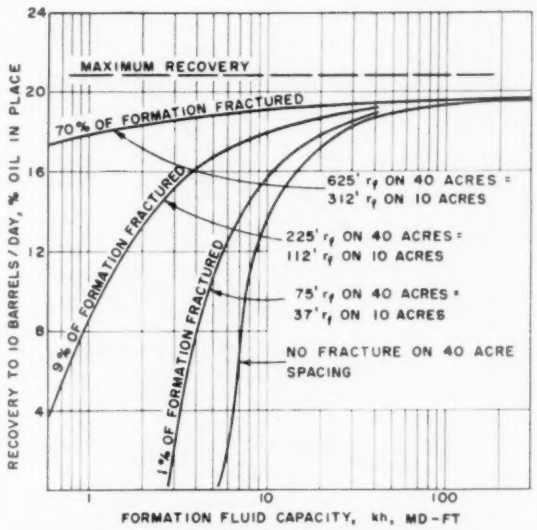

FIG. 7 — RECOVERIES FROM FRACTURED WELLS.

Oil in place = 400 bbls/acre-ft. Fracture carrying capacity = 30 md-ft. Normal relative permeability and crude characteristics as indicated in the Appendix.

accumulation of solids entrained in the fluids near the well bore rather than low capacity kh, large increases in production and recovery will result if fractures are long enough to penetrate beyond the zone of reduced permeability. However, if the plugging is due to accumulation of material from the reservoir fluid, more plugging can be expected as all fluids produced must converge and flow through the bottleneck formed by the rocks flanking the fracture plus those forming the well. If a deeply penetrating fracture is made, the increase in area through which the fluids must flow is increased tremendously. A 625-ft fracture in a 30-ft formation exposes over 52,000 times as much area as is exposed in a 6-in well bore. Thus, when considering the fracture radius required, deeply penetrating fractures have the added advantage that where solids accumulate at the well bore, production increases can be expected to be sustained for a much longer time.

TREATMENT REQUIREMENTS FOR LONG FRACTURES

The preceding portions of this paper have illustrated that commercially attractive producing rates and recoveries can be obtained from oil bearing formations of extremely low permeability, provided fractures of large areal extent may be created in the productive zone. To complete this analysis of reservoir fracturing, a study was made to determine the treating techniques and materials required to create fractures of this size by hydraulic fracturing.

In this study of treatment requirements, data were collected from several hundred fracturing jobs and analyzed as to pump rates, pressures, volume and viscosity of fracturing fluid, production rate increases, etc. From theoretical considerations and these data, it was concluded that a reasonable estimate of the radius of fracture could be obtained from the following formula:

$$r_f = C\left[Q\sqrt{\frac{\mu t}{K}} \right]^{1/2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Where r_f = radius of fracture, feet

Q = injection rate, gallons per minute

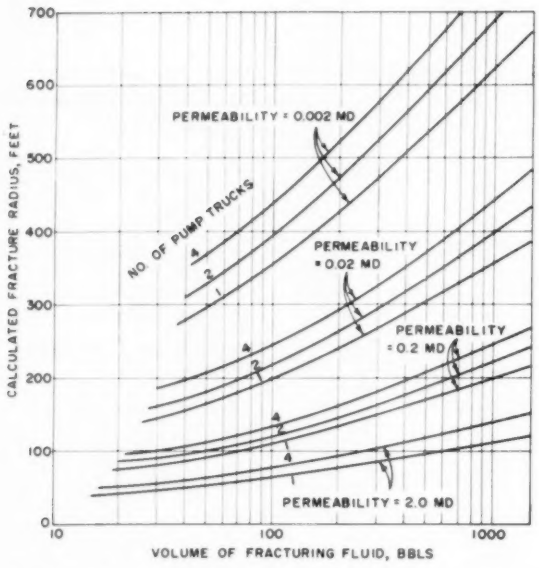

FIG. 8 — FRACTURES CREATED BY HYDRAULIC FRACTURING TREATMENTS IN LOW PERMEABILITY FORMATIONS. Well depth = 4,000 ft (C = 0.15). Fracturing fluid viscosity = 200 cp.

μ = fracturing fluid viscosity, cp

t = pumping time while fracturing, minutes

K = formation permeability, darcys

C = a constant which depends upon the confining stress and rock characteristics

In brief, this equation indicates that the higher the fracturing fluid viscosity and the larger the volume of fluid (product of injection rate Q and pumping time t), the larger will be the fracture created; permeability inversely affects the fracture radius, that is, the lower the permeability the larger the fracture. The constant C involves an inverse function of the confining stress, reservoir pressure, rock strength and porosity and may be determined by analysis of field conditions. Actually, the study indicated that the absolute value of the constant C is not essential as it does not vary widely under most treating conditions. For example, the value of the constant C for a 2,000-ft well was found to be 0.16 and for a 10,000-ft well was found to be 0.11.

In actual practice it is often sufficient to utilize the values as commonly measured on conventional viscosimeters for the viscosity term (μ) in Equation (1). Some fracturing fluids, however are characterized by low viscosity and yet exhibit low fluid loss properties due to suspended solid or semi-solid particles. This low fluid loss causes the fluid to behave as one of much higher viscosity, which, in turn, causes larger fractures than would be expected. In such instances the viscosity value used in Equation (1) may be adjusted upwards to account for low fluid characteristics; however, as the purpose of this equation is merely to illustrate that large fractures can be created, it is sufficient to consider any fluid loss characteristics as a safety factor.

Equation (1) allows the fracture radius to be estimated for any given set of treating conditions and also allows the determination of the materials and techniques required to create long fractures. To determine if it is feasible to create fractures of the size discussed in this paper, a hypothetical set of conditions were assumed and substituted in Equation (1). For this analysis, the well depth was assumed equal to 4,000 ft ($C = 0.15$) and the fracturing fluid viscosity was assumed equal to 200 cp which is typical of the viscous oils commonly used in fracturing treatments. The injection rates were expressed as an equivalent number of pump trucks from computed values of friction losses through 2½-in. EUE tubing, pump rates and surface pump pressures. The injection rates from these computations were as follows:

No. of Pump Trucks	Rate Bbls / Min.	Surface Pressure, psi
1	1.75	1,500
2	2.70	1,900
4	4.05	2,400

The pumping time t in Equation (1) was varied from 50 to 500 minutes. The permeability of the formation to be fractured was varied from 0.002 md to 2.0 md.

The results of these calculations are shown on Fig. 8 which is a plot of volume of fracturing fluid versus fracture radius. From this figure, it may be seen that the tighter the formation the larger the fracture created under any given set of treating conditions. Also, illustrated on Fig. 8 is the increase in fracture radius with increasing injection rates (pump trucks) and fracturing fluid volumes. Finally, Fig. 8 illustrates that fractures of the size needed in very low permeability formations are well within the reach of present day treating practices.

EXAMPLES OF FRACTURING RESULTS

To illustrate the effect of large radius of fractures in tight formations, the following examples are given.

Wells "A" and "B" were open hole completions producing from a tight formation. The formation was a 125-ft lime with a permeability of about 1/3 of a md. Both wells had been acidized when initially completed but the rate of production after several years had declined to about 2 BOPD and it was decided to treat the wells to stimulate production.

Well "A" was treated with a small volume hydraulic fracture treatment. This treatment consisted of 1,250 gals. of gelled hydrocarbon containing about 1/6 of a pound of sand per gallon of gel. Initial production

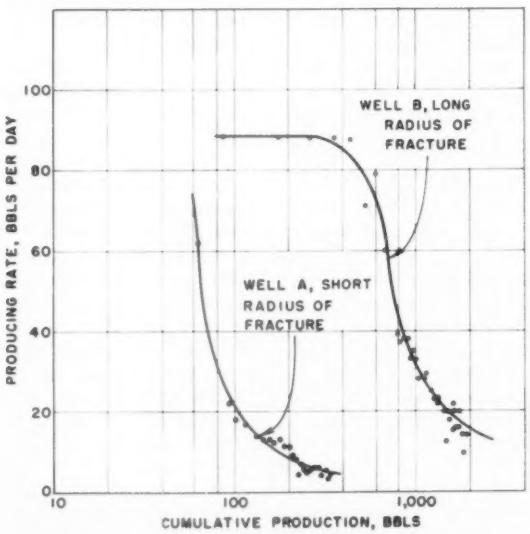

FIG. 9 — PRODUCTION RATE DECLINE FOLLOWING FRACTURE TREATMENT.

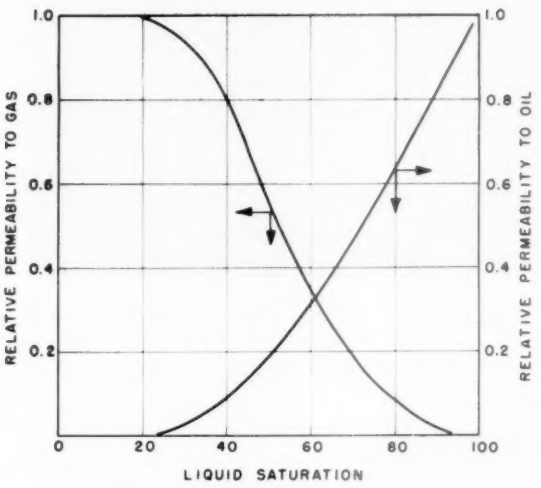

FIG. 10 — ASSUMED RELATIVE PERMEABILITY CHARACTERISTICS.

after treatment was high but rapidly declined as indicated on Fig. 9.

Well "B" was treated with 8,400 gals. of No. 5 fuel oil containing approximately 1 lb of sand per gallon of fuel oil. When this well was placed on production, a high rate of production was maintained for several days and then production declined as shown on Fig. 9.

Productivity index tests were not run on these wells. However, on the assumption that a constant bottom hole pressure was maintained following the time when the wells were again placed on production, production rate is a direct measure of productivity index; therefore, it can be reasoned that Fig. 9 is substantially equivalent to Fig. 6. The economic abandonment rate of these wells was approximately 2 BOPD.

In summary, the results of the study presented in this paper indicate that, though a formation is of very low permeability, substantial recovery at commercially attractive rates can be obtained by making a long radius fracture. These findings mean that in the search for oil, less attention need be given to the permeability of reservoir rocks; it is necessary only to find saturated

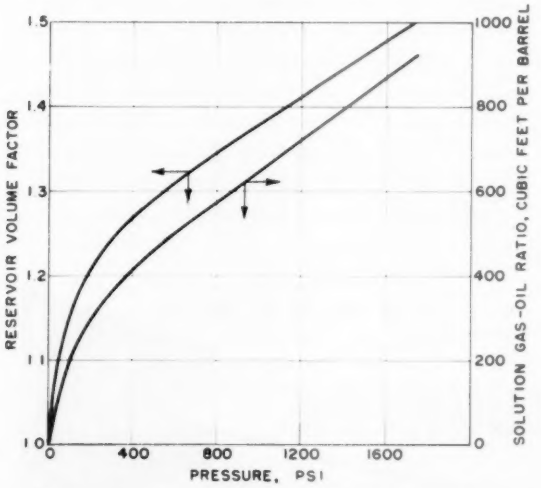

FIG. 11 — ASSUMED CRUDE CHARACTERISTICS.

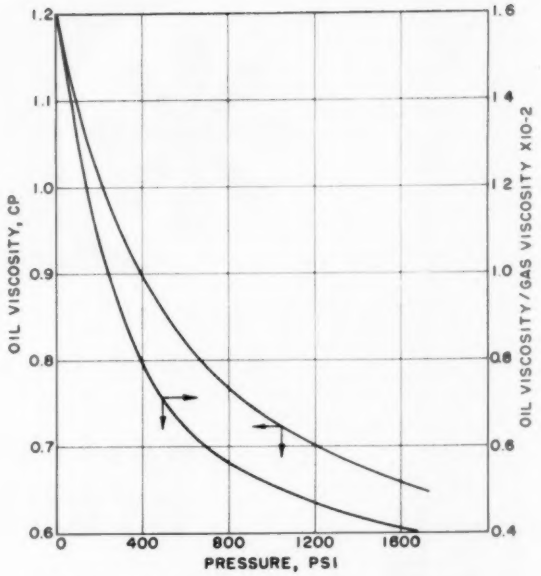

FIG. 12 — ASSUMED RESERVOIR VISCOSITIES.

pore space of sufficient quantity. If sufficient permeability does not exist in the reservoir rock for production at commercial rates, the oil can still be recovered at attractive rates of production by creating a long radius fracture.

CONCLUSIONS

1. The formation permeability below which commercially attractive producing rates and recovery cannot be obtained is extremely low, provided at least one deeply penetrating fracture is created in every continuous reservoir penetrated by a well.

2. In order to increase substantially commercial recovery from extremely tight formations (capacity less than about 50 md-ft), it is necessary to make a sufficiently long fracture such that an appreciable part of the reservoir rock flanks the fracture.

3. Fractures of the length necessary to increase recovery in low permeability formations may be created by present day treating techniques.

4. Very long fractures in tight formations in addition to increasing recovery, will permit relatively high rates of production over most of the well's producing life.

5. Initial potential tests do not indicate the effectiveness of deeply penetrating fractures. They indicate the fracture flow capacity but not the penetration.

ACKNOWLEDGMENT

Acknowledgment is made to the management of the Stanolind Oil and Gas Co. for permission to publish the results of this investigation.

APPENDIX

In order to determine the effect of reservoir fracturing on recovery, certain crude and rock characteristics were assumed. These characteristics given as Figs. 10, 11, and 12, were not chosen to simulate any particular reservoir but were intended to permit evaluation of the relative importance of the variables affecting recovery from fractured wells. Oil in place was arbitrarily set at 400 bbls/acre-ft. ★★★

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INTERRELATION of RESISTIVITY and POTENTIAL of SHALY RESERVOIR ROCK

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ABSTRACT

Both the abnormal resistivity exhibited by shaly reservoir materials and their potential are due to adsorption of ions. Interrelationships between the two have been derived and verified by laboratory results. These relations which have resulted from this work may be used in a qualitative manner to estimate whether or not a particular shaly reservoir contains hydrocarbons, and also to estimate the porosity of shaly sands.

INTRODUCTION

In spite of the progress which has been made in the last decade toward a better understanding and utilization of the electric log, there remain a number of problems in the interpretation of the log. One of these which is often troublesome is that of divining the nature of the fluids in sandstones or carbonate rocks which contain appreciable amounts of shale.

It was shown by Patnode and Wyllie[1] in 1949 that shaly rocks exhibit an abnormally low resistivity when saturated with solutions of low ionic concentrations. This phenomenon has been demonstrated to be due to the adsorptive properties of shale or clay in the rock.[2]

In estimating the fluid content of shaly sands or carbonates from the electric log, it is desirable and sometimes necessary to correct for the abnormally low resistivity. A similar correction is likewise often necessary if attempts are made to estimate the porosity of a stratum from resistivity measurements. The correction may be made from data obtained on core samples and from information on salinity of interstitial water. Cores, however, are not always available. Moreover, even if cores are at hand, their examination is time-consuming. It would be most desirable, therefore, to make corrections of this nature from the log itself. Since both the abnormal resistivity and the potential[3] are consequences of the adsorption of ions on shale, it should be possible to utilize the potential curve to give better interpretation of resistivity data obtained in logging shaly materials. The work described in following sections was directed toward this end.

THEORY

Relation of Resistivity of Shaly Reservoir Rock to Adsorptive Properties

In discussing the effect which the presence of shale or clay exerts on the resistivity of a reservoir rock, it is convenient to make use of the *resistivity factor*.[4,5] This quantity has been defined as the ratio of the resistivity of the rock when it is completely saturated with an electrolyte to the resistivity of the electrolyte itself.

When the rock, such as a clean sand or carbonate, is free of shale the resistivity factor is virtually independent of the ionic concentration of the electrolyte used to saturate the sample, so that

$$F = R_o/R_w = \text{constant for a clean rock} \quad . \quad . \quad (1)$$

where F is the resistivity factor,

R_o is the resistivity of the rock saturated with electrolyte, and

R_w is the resistivity of the electrolyte.

When the rock contains argillaceous material, the resistivity factor as defined above is no longer independent of the concentration of the electrolyte used to saturate the rock, but decreases as the ionic concentration of the electrolyte decreases.

In explanation of this behavior, it is instructive to consider a sample of shaly porous rock placed in contact with a large volume of a dilute electrolyte. The sample is considered to become saturated with the electrolyte, and to attain equilibrium with it. As a result of adsorption by the shale surfaces within the rock, there is a greater concentration of ions in the solution adjacent to the shale particles in the interstices of the sample than there is in the external solution with which the

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office Sept. 2, 1953. Paper presented at the Petroleum Branch Fall Meeting in Dallas Oct. 19-21, 1953.

rock is in contact. For brevity, the solution within the pores of the rock may be termed the "interstitial solution" and that external to the rock and in equilibrium with it the "equilibrium solution."

As ordinarily determined, the resistivity factor is the ratio of the resistivity of the saturated rock to the resistivity of the *equilibrium solution*. It is this factor which decreases for a shaly sample as the electrolyte concentration decreases. On the other hand, it may be assumed that the ratio of sample resistivity to resistivity of *interstitial solution* does not vary with concentration of the electrolyte if the internal dimensions do not change, or that

$$F_o = \frac{R_o}{R_{wi}} = \text{constant for any particular rock} \quad (2)$$

where R_{wi} is the resistivity of the interstitial solution, and

F_o is the resistivity factor.

The distinction between use of the resistivity of the interstitial solution, on the one hand, and that of the equilibrium solution, on the other, in determining the resistivity factor makes it necessary to redefine the resistivity factor, F_o, as the ratio of sample resistivity to resistivity of *interstitial solution*, and to introduce the apparent resistivity factor, F, as the ratio of resistivity of sample to that of the equilibrium solution.

Even for very shaly sands or carbonates F approaches F_o as the equilibrium solution becomes more concentrated, indicating that the concentrations of interstitial and equilibrium solutions differ little at high electrolyte concentration.

By eliminating the resistivity of the sample, R_o, between Equations (1) and (2), the following equation is obtained:

$$F = F_o \frac{R_{wi}}{R_w} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The conductivity of the solution in the pores of an argillaceous rock may be considered as the sum of the conductivity of the equilibrium solution, $\frac{1}{R_w}$, and an excess double-layer conductivity, $\frac{1}{Z}$, or

$$\frac{1}{R_{wi}} = \frac{1}{R_w} + \frac{1}{Z} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Combining Equation (4) with (3), there results

$$\frac{F_o - F}{F} = \frac{R_w}{Z} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The charge on clay surfaces within the rock imparted by adsorbed negative ions or other phenomena results in an increased concentration of positive contra-ions in the interstitial solution. This increase may be approximated for univalent ions by

$$\Delta n = A\sigma \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where Δn is the increase in positive ion concentration,

σ is the charge density on the clay surface, and

A is a constant.

The added conductivity that results from these positive ions, neglecting any changes in negative ion concentration in the interstitial solution, is given by

$$\frac{1}{Z} = A'\sigma\mu_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where μ_1 is the mobility of the positive ion, and

A' is a constant.

The conductivity of the equilibrium solution, expressed in terms of concentration of univalent ions and ionic mobilities, is given by

$$\frac{1}{R_w} = en(\mu_1 + \mu_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where n is the ionic concentration in the equilibrium solution, respectively, and e is the ionic charge.

Substituting Equations (7) and (8) into Equation (5), there results

$$\frac{n}{\sigma}\frac{(F_o - F)}{F} = \frac{A'\mu_1}{e(\mu_1 + \mu_2)} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Writing Equation (9) for two solutions of different ionic concentrations, n_1 and n_2, with the assumption that the ratio $\frac{\mu_1}{\mu_1 + \mu_2}$ does not vary with concentration,

$$\left(\frac{F_o - F_2}{F_2}\right)\left(\frac{F_1}{F_o - F_1}\right) = \frac{\sigma_2}{\sigma_1}\frac{n_1}{n_2} \quad . \quad . \quad . \quad (10)$$

This relation alone does not permit computation of the extent of abnormality, since σ cannot be measured directly. The quantity σ, however, can be related to the potential, as shown in the following section.

Relation of Mounce Potential to Adsorptive Properties

It has been shown in a recent publication[5] that the Mounce potential, observed when a sample of shaly material is interposed between solutions of different ionic concentrations, is the sum of three potentials — two so-called phase boundary potentials, and a diffusion potential. The latter component is usually of minor importance in shaly materials. The Mounce potential is the principal component of the potential recorded by the electric log.[6]

In the work on the Mounce potential to which reference is made above, the phase boundary potential is related to a quantity termed n_o, which reflects the amount of adsorption of negative ions by the shale. The quantity n_o is expressed as a charge density per unit volume, and is related to σ, the surface charge density of Equation (10), by a constant of proportionality for any particular sample.

In some of the previous work on the potential it has been necessary to assume, to avoid complexities in mathematics, that n_o is constant for a given rock sample, even though it has been realized that n_o is a function of concentration of the electrolyte. For the present purpose n_o and its counterpart σ are considered to be functions of concentration.

An analytical solution for the phase boundary potential and the diffusion potential, allowing for a variation of n_o with concentration, requires a knowledge of proper boundary conditions, which are determined by the geometry of the rock, and of a functional relation between n_o and concentration. These difficulties, as well as that introduced by the nonlinearity of the differential equation that results, present obstacles to a rigorous analytical approach.

To circumvent these difficulties, another approach may be made. The Mounce potential, $\Delta\Phi$, can be described by

$$\Delta\Phi = g(n_1, n_2, \sigma_1, \sigma_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

The potential existing between a charged rock surface and the equilibrium solution is also completely determined by the surface charge and solution concentration, so that

$$\Delta\Phi = f(\Phi_{s_1}, \Phi_{s_2}, \Phi_d) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where Φ_{s_1}, Φ_{s_2} are, respectively, surface potentials at concentrations n_1 and n_2, and

$\Phi_d = 0.2 \ln \frac{n_1}{n_2}$, the normal diffusion potential for NaCl.

As a trial solution, the Mounce potential is considered to be a linear function of the surface and diffusion potentials, giving

$$\Delta\Phi = \Phi_{s_1} - \Phi_{s_1} + \Phi_d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

An equation for the surface potential of a flat charged plate is available from Verwey and Overbeek.[7] For the conditions described in the reference, the potential is given by

$$\sin h \frac{\Phi_s}{2} = \sigma \left[\frac{\pi}{2nDkT} \right]^{1/2} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where Φ_s is the surface potential in units of $\frac{kT}{\epsilon}$ referred to the equilibrium solution,

k is Boltzmann's constant,
D is the dielectric constant,
n is the concentration of ions in the equilibrium solution,
T is the temperature in °K,
σ is the surface charge/cm.^{2}, and
ϵ is the charge on an electron.

Substituting Equation (14) into (13), with the approximation that

$$e^{-\Phi_s/2} >> e^{\Phi_s/2},$$

there results

$$\Delta\Phi = 2 \ln \frac{\sigma_1}{\sigma_2} + 0.8 \ln \frac{n_2}{n_1} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

The approximation is necessary only to bring Equation (14) into a form having an explicit solution for $\frac{\sigma_1}{\sigma_2}$.

Equation (13) is an assumed form of solution to Equation (12). It cannot be verified experimentally by potential determinations alone, but elimination between Equations (15) and (10) of terms containing the surface charge does provide an expression for the Mounce potential and the resistivity factor containing measurable quantities.

Relation Between Potential and Resistivity Factor

Simultaneous solution of Equations (15) and (10) yields

$$\ln \left[\frac{(F_o - F_2)}{F_2} \frac{F_1}{(F_o - F_1)} \right] = \frac{-\Delta\Phi}{2} - 0.6 \ln \frac{n_2}{n_1} \quad (16)$$

with F_2, F_1, $\Delta\Phi$, n_1, and n_2 having values that may be determined experimentally.

Other solutions containing similar terms might also be chosen. The only criteria for selection are that the equations contain useful quantities and be subject to experimental verification. One other such equation can be obtained as follows:

Equation (3) may be written in the form

$$\frac{F_o}{F} = \frac{\rho}{\rho_1} = \frac{\bar{\mu}_1 \bar{n}_1 + \bar{\mu}_2 \bar{n}_2}{n(\mu_1 + \mu_2)} \quad . \quad . \quad . \quad . \quad (3a)$$

where n_1 and n_2 are the positive and negative ion concentrations in the core, the bar denoting an average taken to satisfy Equation (3a), and μ_1 and μ_2 are the ionic mobilities in the core, similarly averaged.

The concentration of positive ions, n_1, and negative ions, n_2, may be related to the equilibrium concentration, n, by Boltzmann's distribution equations

$$n_1 = \overline{ne^{-\Phi b}}$$
$$n_2 = \overline{ne^{\Phi b}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

where Φb is the potential in the core referred to the equilibrium solution in units of kT/ϵ.

Substituting Equation (17) in (3a) gives

$$\frac{F_o}{F} = \frac{\bar{\mu}_1 \overline{e^{-\Phi b}} + \bar{\mu}_2 \overline{e^{\Phi b}}}{\mu_1 + \mu_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

If it be assumed, for convenience in computations, that $\overline{e^{\Phi b}}$ is negligible and that the ratio $\frac{\bar{\mu}_1}{\mu_1 + \mu_2}$ does not vary with concentration, then

$$\frac{F_o}{F} = \text{constant } \overline{e^{-\Phi b}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

When F is taken at two different ionic concentrations, F_o may be eliminated to give

$$\frac{F_2}{F_1} = \frac{\overline{e^{-\Phi b_1}}}{\overline{e^{-\Phi b_2}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

It is again necessary to assume a form of the solution to an equation in order to relate the resistivity factor to the Mounce potential. A convenient choice is that

$$\ln \frac{F_2}{F_1} = \ln \overline{e^{-\Phi b_1}} - \ln \overline{e^{-\Phi b_2}} = \Delta\Phi \quad . \quad . \quad (21)$$

where $\Delta\Phi$ is the Mounce potential.

Because of the methods employed to obtain Equations (16) and (21) the usefulness of the equations can only be determined by application to experimental data. The above equations have been used to correlate experimental data, and the results are presented in the following section.

EXPERIMENTAL

Procedure

In order to test experimentally the relations given by Equations (16) and (21), determinations were made of the apparent resistivity factors and Mounce potentials given by shaly sands from several different strata and localities. No shaly carbonates were examined.

Small cylindrical plugs, 1-in. in diameter and averaging about 1-in. in length, were cut from well cores. The axis of each cylinder was parallel to the bedding plane. The samples were extracted with organic solvents, air-dried, and saturated with 5N sodium chloride solution. Each sample was then placed in a Hassler type core holder, and 5N sodium chloride solution was passed through the core until the resistivity, as determined by a four electrode alternating-current measuring system, was constant. Successively more dilute salt solutions were passed through the core, and resistivity measurements were made until equilibrium was attained at each concentration, as shown by constancy of resistivity.

Mounce potential measurements were made on each sample after all resistivity determinations had been completed. For this purpose, solutions of the desired concentrations were placed in contact with the ends of the sample, and readings were taken after the potential became constant.

TABLE 1 — EXPERIMENTAL RESISTIVITY FACTOR DATA

Concentration of Equilibrium Solution eq. /liter	Sample S-1 Formation: Frio Source: Kleberg Co., Texas Depth: 6,000 ft Porosity: 23 %	Sample R-1 Formation: McElroy Source: Live Oak Co., Texas Depth: 4,560 ft Porosity: 26.8%	Sample S-2 Formation: Frio Source: Kleberg Co., Texas Depth: 6,000 ft Porosity: 18.3%	Sample W-2B Formation: Wilcox Source: McMullen Co., Texas Depth: 6,860 ft Porosity: 18.2%	Sample KD-1 Formation: Frio Source: Brooks Co., Texas Depth: 6,165 ft Porosity: 15.5%	Sample P-1 Formation: Frio Source: Kennedy Co., Texas Depth: 8,100 ft Porosity: 20.0%	Sample P-A Formation: Spraberry Source: Upton Co., Texas Depth: 7,000 ft Porosity: 13.6%	Sample 8 Formation: Stevens Source: Elk Hills California Depth: 7,500 ft Porosity: 17.6%
n	F	F	F	F	F	F	F	F
5.0	15.3	9.7	20.0	21.1	30.4	21.8	44.7	26.0
1.0	....	....	....	....	....	15.7	40.7	19.7
0.97	13.5	8.7	16.1	20.0	26.0	....	....	....
0.31	....	7.8	....	....	21.8	....	....	....
0.138	9.7	....	10.2	....	....	....	....	....
0.1	....	....	....	....	....	7.65	36.4	10.0
0.087	....	5.9	....	....	14.5	....	....	....
0.06	....	....	....	13.5	....	....	....	....
0.025	6.3	3.1	4.6	....	....	....	....	....
0.01	....	....	....	8.0	4.8	2.26	28.2	4.10
0.006	3.6	....	....	....	....	....	....	....
0.005	....	....	1.3	6.6	3.2	1.45	24.5	3.15

RESULTS

Sample description and source, data on porosity, and apparent resistivity factors at various electrolyte concentrations are given in Table 1. Table 2 presents data on Mounce potentials of the same samples.

Since the concentrations of solutions used in determining the apparent resistivity factors and the Mounce potentials generally differed somewhat, it was necessary to interpolate in order to obtain data for testing Equations (16) and (21).

Table 3 shows interpolated values of apparent resistivity factor and of potential for each sample at different pairs of values for electrolyte concentrations.

Tabulated in this table are the values of F_o computed by use of Equation (16). As criteria of the manner in which the equation agrees with the experimental data, the computed values of F_o should be (1) reasonably constant as computed from different pairs of electrolyte concentrations, and (2) equal to or slightly greater than the values of resistivity factor determined by use of 5N solution. Although F_o computed from Equation (16), gives a reasonably good check of the equation, the calculated values are not entirely independent of electrolyte concentration. However, slight modification of the coefficient of the concentration term in Equation (16) from 0.6 to 0.5 results in a more satisfactory fit of the data. It is interesting to note that this is equivalent to omitting the diffusion potential. So modified, the equation becomes

$$-2ln\left(\frac{F_o-F_2}{F_2}\right)\left(\frac{F_1}{F_o-F_1}\right)=\Delta\Phi+ln\frac{n_2}{n_1}. \quad (22)$$

Values of F_o computed by the above equation are also shown in Table 3. The consistency of these data indicates that Equation (22) is preferable for estimation of the resistivity factor.

A comparison of Equation (21) with experimental data is shown in Fig. 1. In this figure the Mounce potential is plotted against the logarithm of F_2/F_1. As shown in this figure, the experimental data are in excellent agreement with Equation (21).

Both Equations (22) and (21) relate Mounce potential to the resistivity of the sample. It may be noted that these equations can be combined by eliminating the Mounce potential to yield a very simple relation. When this is done and the solution resistivities are substituted for the solution concentrations, the following equation results

$$\frac{F_o-F_2}{F_o-F_1}=\left(\frac{R_{o_2}}{R_{o_1}}\right)^{0.5}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

The above equation was tested by solving for F_o at various values of electrolyte concentrations. In order that the values of F_o, computed from Equation (23), may be compared with the resistivity factors determined from Equation (16) and (22), they are also tabulated in Table 3. The average values of F_o computed by use of Equation (23) are in good agreement with those obtained by use of Equation (22).

It is possible to make an additional indirect check on Equations (22) and (23) by using the values of F_o computed from them to calculate the porosity by use of the relation[8]

$$F_o=0.62\phi^{-2.15}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

where ϕ is the porosity, expressed as a fraction.

The porosities so computed can then be compared with the measured porosities. A comparison is shown in Table 4 of the measured porosities with those calculated from Equation (24) using average values of F_o obtained by employing, respectively, Equations (22) and (23).

APPLICATION TO ELECTRIC LOG INTERPRETATION

Of the various problems which arise in the interpretation of electric logs of shaly rocks, perhaps the most important is that of estimating whether or not a particular stratum contains oil or gas. Another problem

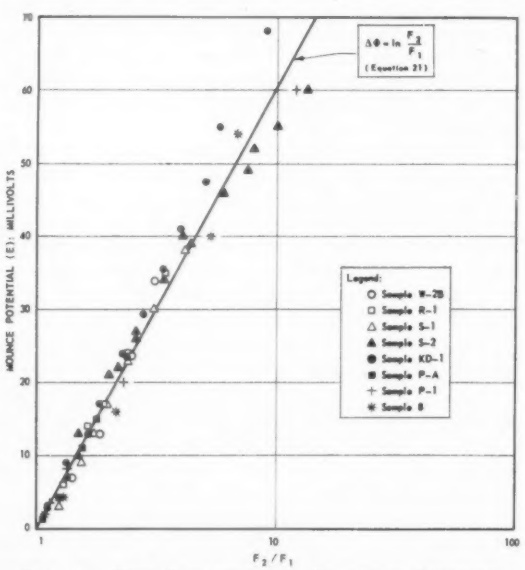

FIG. 1 — THE RELATIONSHIP BETWEEN MOUNCE POTENTIAL AND THE RESISTIVITY FACTOR RATIO.

which is often encountered is that of estimating the porosity.

The approach to the first problem, that of deciding whether a shaly zone may contain hydrocarbons, consists of first estimating the resistivity of the stratum filled only with formation water and of then comparing this resistivity with the resistivity indicated by the electric log. If the latter is significantly higher, it is logical to assume the presence of oil or gas.

To estimate the resistivity which the shaly zone would have if completely saturated with formation water, Equation (21) may be applied. For this purpose, the term $\Delta\Phi$ must be expressed in terms of the potential read from the electric log, referred either to a shale base line or to the value for a clean sand or carbonate in the immediate vicinity of the bed of interest.

If a clean sand is used as a reference for the potential, it is necessary to know (1) the resistivity of the mud filtrate, (2) the resistivity of the formation water, (3) the resistivity of the invaded zone, and (4) the difference in potential read opposite the clean sand and the bed of interest. If the shale base line is used as a reference, it is not necessary to know the resistivity of the formation water or of the mud filtrate.

Laboratory results have indicated[3,9] that the Mounce potential of shales may be considered virtually independent of the character of the shale at relatively low electrolyte concentrations. It is possible that the maximum electrolyte concentration under which this condition prevails depends upon the particular shale; tentatively, it may be assumed that the upper limit is possibly in the range of 25,000-100,000 ppm sodium chloride. Assuming that the Mounce potential under these conditions is not dependent upon the type of shale

$$E_{shale} = \frac{kT}{\epsilon} \ln \frac{n_2}{n_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

where E_{shale} is the Mounce potential across the shale in mv.

If the above equation is combined with Equation (21) so that the resulting equatior contains the difference in potential between the shale base line and the shaly bed under consideration, then

$$E = \frac{kT}{\epsilon} \ln \frac{n_2}{n_1} \frac{F_1}{F_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

where E is the difference in potential in millivolts between the shale and the shaly bed on the potential curve.

When the solution resistivities are substituted for concentrations, and the logarithm and temperature are changed to conform with common electric log usage, the equation becomes

$$E = 0.11(460 + T) \log_{10} \frac{R_{xo}}{R_o} \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

where T is temperature in °F.,

R_{xo} is, in this case, resistivity of the invaded zone, and

R_o is, in this case, resistivity of the bed completely saturated with formation water.

The assumption that the log potential is equivalent to the Mounce potential tacitly implies that there is a negligible effect due to any streaming potential, that the salt in the drilling mud filtrate and formation water is sodium chloride, and that geometrical corrections of the type discussed by Doll[10] are not significant.

In practice, R_{xo} must be determined from an electrode configuration which has close spacing, such as that of a "microlog" tool.

In estimating the porosity of a shaly bed, the most direct method utilizes Equations (23) and (24). The latter equation requires the use of the true resistivity factor, which is obtained from the former equation.

In applying Equation (23), F_1 is designated as the apparent resistivity factor of the invaded zone, which has resistivity R_{xo}. These quantities are determined from log resistivity measurements made with close electrode spacing and from a knowledge of the mud filtrate resistivity at formation temperature. F_2 is designated as the apparent resistivity factor of the uninvaded zone, and R_o is the resistivity of this zone when it is completely saturated with formation water. If the zone is known to contain no hydrocarbons, R_o may be estimated from log measurements. In the case in which there is no positive knowledge of the fluid content, R_o may be estimated by use of Equation (27), as described in foregoing paragraphs. To compute F_2, it is necessary to know the resistivity of formation water and to utilize R_o.

Although it is apparent that the relations discussed in this report may be useful in the interpretation of the electric log, it must be emphasized that they are subject to limitations. First, as in the case of any relations proposed as aids to log interpretations, they must be proved by actual usage under a wide variety of conditions. Second, the data they require are subject to errors in measurement. In consequence, it is necessary

TABLE 2 – EXPERIMENTAL MOUNCE POTENTIAL DATA

Concentration Test Solution eq. /liter n_2	Concentration Reference Solution eq. /liter n_2	Sample S-1 E, mv.	Sample R-1 E, mv.	Sample S-2 E, mv.	Sample W-28 E, mv.	Sample KD-1 E, mv.	Sample P-1 E, mv.	Sample P-A E, mv.	Sample 8 E, mv.
0.001	1.5	....	....	....	60	....	....	....	....
0.002	1.5	51	....	72	52	83	....	....	....
0.005	1.5	38	60	60	34	68	60	15	54
0.01	1.5	30	45	51	24	56	....	11	40
0.02	1.5	....	34	....	....	42	....	....	....
0.05	1.5	17	22	27	10	27	....	....	....
0.1	1.5	....	14	18	....	18	20	4	16
0.2	1.5	4	10	10	....	10	....	....	....
0.5	1.5	....	....	....	....	....	....	3	....
1.0	1.5	....	....	0.5	....	....	3	1	2
0.001	0.128	....	....	....	....	74	....	....	....
0.002	0.128	....	....	....	....	64	....	....	....
0.005	0.128	....	....	....	....	48	....	....	....
0.01	0.128	....	....	....	....	36	....	....	....
0.02	0.128	....	....	....	....	25	....	....	....
0.05	0.128	....	....	....	....	11	....	....	....
0.2	0.128	....	....	....	....	−5	....	....	—
0.005	0.1	....	....	45	....	....	....	....	....
0.02	0.1	....	....	25	....	....	....	—	—
1.75	0.1	....	....	−16	....	....	....	....	....
5.0	0.1	....	....	−19	....	....	....	....	....

TABLE 3 — RESISTIVITY FACTORS COMPUTED FROM MOUNCE POTENTIAL AND RESISTIVITY DATA

Sample No.	Solution Concentrations eq./liter n_1	n_2	Apparent Resistivity Factors F_1 (with n_1)	F_2 (with n_2)	Mounce Potential E, mv.	Computed Resistivity Factors F Eq. (16)	F Eq. (22)	F Eq. (23)
S-1	0.005	1.5	3.3	13.9	36.5	14.7	15.3	15.7
S-1	0.01	1.5	4.4	13.9	29.0	14.8	15.5	15.9
S-1	0.04	1.5	7.2	13.9	17.0	15.1	15.9	16.4
S-1	0.1	1.5	9.1	13.9	11.0	15.4	16.1	16.6
S-1	0.3	1.5	11.3	13.9	5.0	15.8	16.6	17.0
S-1	...	5.0	...	15.3	Average (F_∞)	15.2	15.9	16.3
R-1	0.025	1.5	3.0	9.2	28.0	10.3	11.1	11.5
R-1	0.04	1.5	4.0	9.2	21.0	10.3	11.0	11.4
R-1	0.06	1.5	4.8	9.2	16.5	10.2	10.9	11.3
R-1	0.1	1.5	5.8	9.2	11.5	10.3	10.8	11.2
R-1	0.2	1.5	7.6	9.2	5.0	9.9	10.2	10.6
R-1	...	5.0	...	9.7	Average (F_∞)	10.2	10.8	11.2
S-2	0.005	0.1	1.3	9.1	45.0	16.3	23.4	22.8
S-2	0.02	0.1	4.0	9.1	21.0	16.0	19.8	21.6
S-2	0.005	1.5	1.3	17.4	60.0	19.9	22.4	23.2
S-2	0.06	1.5	7.3	17.4	24.0	20.0	21.6	23.2
S-2	0.1	1.5	9.1	17.4	17.5	20.4	21.9	23.1
S-2	...	5.0	...	20.0	Average (F_∞)	18.5	21.8	22.8
W-28	0.005	1.5	6.6	20.4	34.0	21.1	21.8	22.4
W-28	0.01	1.5	8.1	20.4	24.0	21.5	22.2	22.7
W-28	0.02	1.5	10.0	20.4	17.0	21.7	22.4	23.0
W-28	0.1	1.5	15.1	20.4	6.5	22.0	22.7	23.2
W-28	0.2	1.5	16.9	20.4	2.5	22.1	22.8	23.2
W-28	...	5.0	...	21.1	Average (F_∞)	21.7	22.4	22.9
KD-1	0.005	0.128	3.2	16.3	47.5	21.4	24.9	28.6
KD-1	0.06	0.128	12.0	16.3	9.0	27.6	31.6	37.0
KD-1	0.005	1.5	3.2	27.6	68.0	29.6	31.4	34.1
KD-1	0.06	1.5	12.0	27.6	24.0	31.4	33.9	36.4
KD-1	0.1	1.5	15.0	27.6	17.5	32.0	34.0	36.2
KD-1	...	5.0	...	30.4	Average (F_∞)	28.2	31.2	34.4
P-1	0.005	1.5	1.45	17.5	60.0	20.0	22.2	22.8
P-1	0 01	1.5	2.26	17.5	44.0	20.5	23.4	23.0
P-1	0.10	1.5	7.65	17.5	20.0	21.8	24.2	25.0
P-1	...	5.0	...	21.8	Average (F_∞)	20.8	23.3	23.6
P-A	0.005	1.5	24.5	43.0	15.0	43.8	44.5	45.0
P-A	0.01	1.5	28.2	43.0	11.0	44.0	44.7	45.0
P-A	0.10	1.5	36.4	43.0	4.0	44.2	45.6	45.7
P-A	...	5.0	...	44.7	Average (F_∞)	44.0	44.9	45.2
8	0.005	1.5	3.15	21.5	54.0	23.0	24.6	25.8
8	0 01	1.5	4.10	21.5	40.0	23.6	26.0	26.4
8	0.10	1.5	10.0	21.5	16.0	26.6	29.4	29.2
8	...	5.0	...	26.0	Average (F_∞)	24.4	26.6	27.1

to apply these relations with caution, and it is desirable not to condemn any stratum as being non-productive solely on the basis of results obtained by their use.

CONCLUSIONS

1. The adsorptive characteristics of shaly reservoir materials can be used to relate the Mounce potential and abnormal conductivity of these materials. The relations so derived have been verified by laboratory results.

2. The relations resulting from this work may be used qualitatively to estimate whether or not a particular shaly stratum contains oil or gas.

3. These relations may be also used in the estimation of porosity of shaly sands.

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TABLE 4

Sample No.	Measured Porosity Per Cent	Computed Porosity, Per Cent Equation (22)	Equation (23)
S-1	23.0	22.2	21.8
R-1	26.8	26.5	26.0
S-2	18.3	19.2	18.8
W-28	18.2	18.8	18.7
KD-1	15.5	16.2	15.4
P-1	20.0	19.0	18.8
P-A	13.6	13.9	13.8
8	17.6	17.8	17.5

★★★

A METHOD for DETERMINATION of AVERAGE PRESSURE in a BOUNDED RESERVOIR

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ABSTRACT

A method has been developed for calculating the average pressure in a bounded reservoir. The reservoir is first divided into the individual drainage volumes of each well, by using the criterion that at steady state each individual drainage volume is proportional to a well's production rate. The average pressure in each drainage volume is then calculated by a method developed in the report. By volumetrically averaging these individual drainage volume pressures, the average pressure in the entire reservoir is obtained.

To calculate the average pressure in each drainage volume, a correction is applied to the ordinary extrapolated pressure, i.e., the pressure obtained by extrapolating to infinite time the linear portion of the graph of closed-in pressure versus $\log[\Delta t/(t+\Delta t)]$, *where* Δt *is the closed-in time and* t *the production time. The correction, which is a function of the production time, is presented in graphical form for different shapes of the drainage area (horizontal cross section of the drainage volume).*

INTRODUCTION

It is important to be able to find the volumetric average pressure in a reservoir so that the size of the reservoir may be determined from material balance calculations. It is also desirable to be able to find the approximate distribution of pressure within a reservoir for detection of fluid movement. The purpose of this paper is to present a method for calculating both the average reservoir pressure and the approximate distribution of pressure within a bounded reservoir — that is, a reservoir with no water drive.

In reservoirs where the pressure builds up rapidly after wells are shut in, the determination of average pressure generally poses little problem, for one often need only average the final buildup pressures. It is when pressure buildup is slow that difficulties arise. For practical and economical reasons, the time allowable for closing in wells is limited. If at the maximum allowable closed-in time the pressure has not reached a constant value (and this is more often the case than is generally realized), calculation of average pressure presents difficulties.

One method which has been used in the past for obtaining an "average" pressure involves the extrapolation to infinite closed-in time of curves of pressure as a function of closed-in time. Contour maps of these extrapolated pressures are used in arriving at an average pressure. In some cases wells are shut in for arbitrary lengths of time, and contours of these arbitrary shut-in pressures are used for calculation. All these methods are somewhat arbitrary and suffer from lack of fundamental theoretical basis. For example, no precise meaning can be given either to the extrapolated or to the arbitrary shut-in pressure. Furthermore, there seems to be no reason why either set of pressures should be contourable. It was because of the vagueness of these old methods and their lack of a sound theoretical basis that the present method for determining average reservoir pressure was developed.

SYMBOLS

A = drainage area of a well, cm²
A_j = drainage area of well j, cm²
A_t = total drainage area of all wells in a reservoir, cm²
c = coefficient of compressibility of fluid at reservoir temperature, atm⁻¹
f = hydrocarbon-filled porosity, fraction
h = net thickness of formation, cm
k = permeability of formation, darcy
p = pressure at a well, atm
p_o = initial reservoir pressure, atm
p^* = pressure obtained by straight-line extrapolation of linear portion of plot of p versus $\log[\Delta t/(t+\Delta t)]$
$\bar{p}$ = volumetric average pressure inside drainage volume of a well
q = volume flow rate at a well, cc/sec at prevailing reservoir conditions
q_t = total volumetric flow rate from a reservoir, cc/sec at prevailing reservoir conditions
r_w = radius of well bore, cm
$T = kt/f\mu cA$
t = corrected time of production of a well, seconds, defined by

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[1]References given at end of paper.
Manuscript received in the Petroleum Branch office Aug. 4, 1953. Paper presented at the Petroleum Branch Fall Meeting in Dallas, Oct. 19-21, 1953.

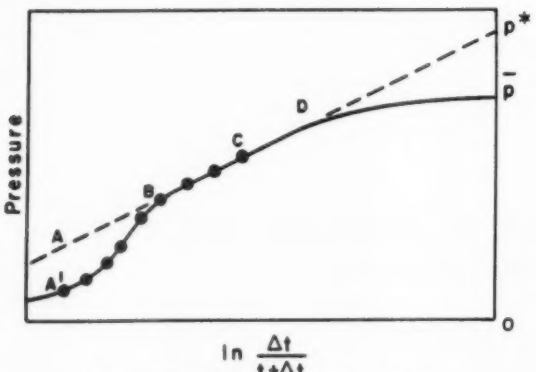

FIG. 1 — PRESSURE BUILDUP CURVE.

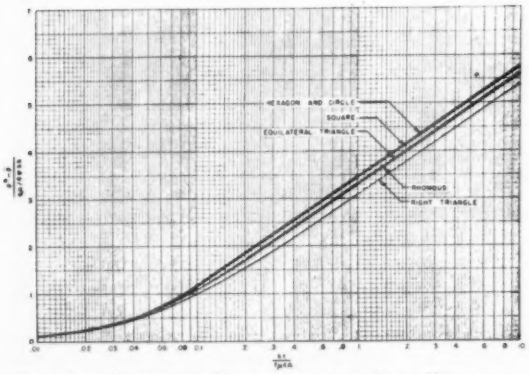

FIG. 2 — PRESSURE FUNCTION FOR ONE WELL IN CENTER OF EQUILATERAL FIGURES.

$$t = \frac{\text{total fluid produced}}{\text{rate of production just before shutting in}}$$

Δt = closed-in time of a well, seconds

v_j = drainage volume of a well j, cc of matrix and pores

v_t = total volume of reservoir, cc of matrix and pores

μ = viscosity at reservoir conditions, cp

log = logarithm to base 10

ln = logarithm to base e

$ln\,\gamma = 0.5772$

Ei = exponential integral: $Ei(-x) = -\int_x^{\infty} \frac{e^{-u}}{u}\,du$

ASSUMPTIONS

It is assumed that the reservoir is horizontal, homogeneous, isotropic, and of uniform thickness. The fluid is assumed to be in a single phase of small and constant compressibility and constant viscosity. However, it is believed that the method developed herein may be applied with good approximation to many bounded reservoirs and fluids encountered in practice, even though they do not strictly obey these assumptions. The presence of a zone of altered permeability immediately around the well bore does not affect the determination of average pressure by this method.

ONE WELL IN A HOMOGENEOUS BOUNDED RESERVOIR

By methods similar to those used by other authors,[2,3,4] it is shown in Appendix I that the pressure-buildup behavior of a single well in the center of a circular reservoir is given by an equation of the form

$$p = p_o + \frac{q\mu}{4\pi kh}\left\{ ln\,\frac{\Delta t}{t+\Delta t} + Y(t+\Delta t) - Y(\Delta t)\right\} \quad . \quad . \quad (1)$$

Equation (1) is plotted in Fig. 1 as line $ABCD\bar{p}$. Because of disturbing effects of flow into casing and tubing after a well is shut in, the initial portion of the curve is normally observed to be curved, as $A'B$. After the effects of inflow die out the buildup plot becomes linear, as along BCD, and then finally flattens toward the average reservoir pressure $\bar{p}$. Now if the observed linear portion BC is extrapolated to the point where $ln[\Delta t/(t+\Delta t)] = O$ (i.e., to infinite closed-in time), a pressure p^* is obtained. Generally p^* has no practical meaning, but knowledge of its value enables calculation of the average pressure $\bar{p}$ in the bounded reservoir. For this purpose the quantity $(p^* - \bar{p})/(q\mu/4\pi kh)$ is introduced as shown in Fig. 2 and derived in Appendix I.

For a given production time in a circular reservoir the value of $(p^* - \bar{p})/(q\mu/4\pi kh)$ can be read from Fig. 2, and after p^* and $q\mu/4\pi kh$ are obtained from the pressure-buildup curve, $\bar{p}$ may be calculated. An example of this will be shown later.

It is also possible to derive values for the function $(p^* - \bar{p})/(q\mu/4\pi kh)$ for boundaries of shapes other than circular and for various positions of the well within by use of the method of images. The general

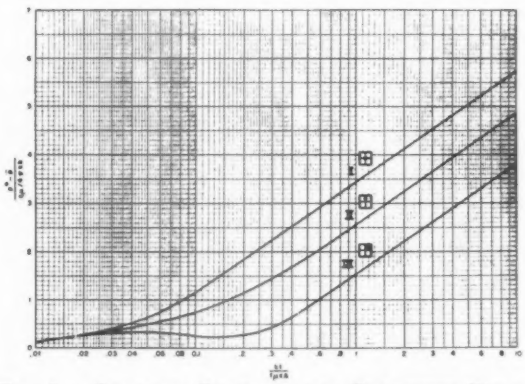

FIG. 3 — PRESSURE FUNCTION FOR DIFFERENT WELL LOCATIONS IN A SQUARE BOUNDARY.

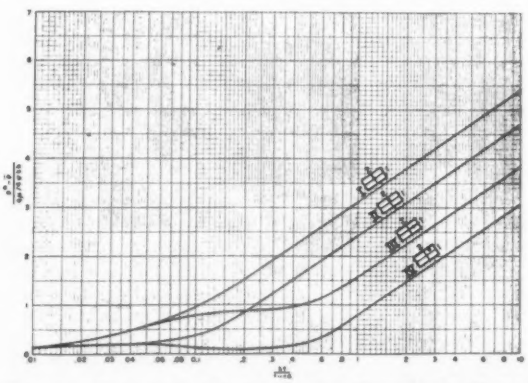

FIG. 4 — PRESSURE FUNCTION FOR DIFFERENT WELL LOCATIONS IN A 2:1 RECTANGULAR BOUNDARY.

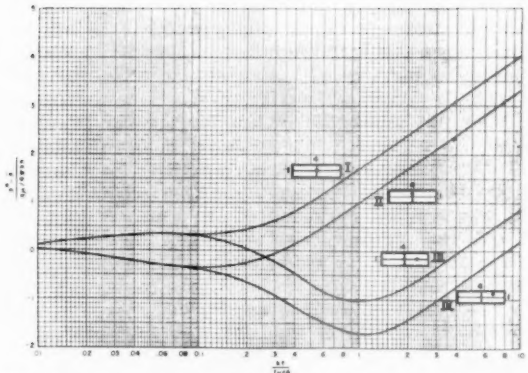

FIG. 5 — PRESSURE FUNCTION FOR DIFFERENT WELL LOCATIONS IN A 4:1 RECTANGULAR BOUNDARY.

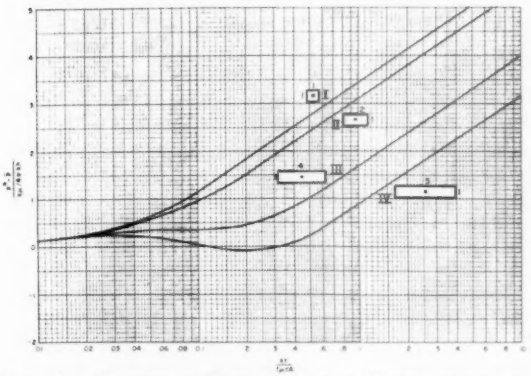

FIG. 6 — PRESSURE FUNCTION FOR RECTANGLES OF VARIOUS SHAPES.

features of the method are given in Appendix II, and the results in Figs. 2 to 8. The application of the results is discussed in the next section. With slight modification Figs. 2 to 8 could also be applied according to the method discussed by Miller, Dyes, and Hutchinson.[3]

The quantity $(p^* - \overline{p})/(q\mu/4\pi kh)$ may be called the pressure correction function. It may be seen from Fig. 2 that when a well is symmetrically located inside symmetrical boundaries, the exact shape of the boundaries has little effect on this function. Thus the curves differ but little, regardless of whether the outer boundaries are in the form of a hexagon, square, rhombus, equilateral triangle, right triangle, or circle. This result gives at least some basis for the often used assumption that the behavior of a circular drainage area may be used to represent the behavior of a square drainage area.

There is a considerable effect of well asymmetry with respect to boundaries as shown by Curves II and III in Fig. 3, and Curves II, III, and IV in Figs. 4 and 5. In these figures the position of the well is indicated by a dot. In general the more asymmetric a well's position with respect to its boundaries, the lower the position of its curve on the graph.

In Fig. 6 the effect of the shape of a rectangular boundary on the pressure correction function is shown. The more asymmetric the shape of the rectangle, the lower the position of its curve on the graph.

In Figs. 5, 6, 7, and 8 the pressure correction function takes on negative values at certain times. In these regions the extrapolated pressure p^* is less than the average pressure $\overline{p}$. This happens because the pressure build-up curve has more than one "hump" in a reservoir of such shape. An illustrative pressure build-up curve for which $p^* - \overline{p}$ is negative is shown by Curve 1, Fig. 9. Curve 2 is the more normal type. These curves are easily obtained by appropriate superposition of the pressure correction function according to Equation (B-3) of Appendix II. It will not often be possible to observe this sort of behavior in practice, however, because only seldom do we have one-well reservoirs. In a multi-well reservoir, well interference effects will tend to mask any such behavior.

BOUNDED RESERVOIRS CONTAINING MORE THAN ONE WELL

In the preceding section a discussion was given of the function $(p^* - p)/(q\mu/4\pi kh)$ for one well inside a boundary. In this section there will be indicated a method of subdividing a reservoir containing more than one well so that the preceding results may be applied.

If there is production at a constant rate from a bounded reservoir containing a fluid of constant compressibility and drained by a single well, after a certain time the rate of pressure decrease, $\partial p/\partial t$, becomes constant at every point and a steady state is reached.[1] Now consider several wells draining from the same reservoir. Since we can superpose the effects of the several wells to get the resultant pressure effect, we will find, after some production time, in this multiwell reservoir, that the rate of pressure decline also becomes constant and equal everywhere. In addition, the volume of the reservoir drained by each well becomes constant.

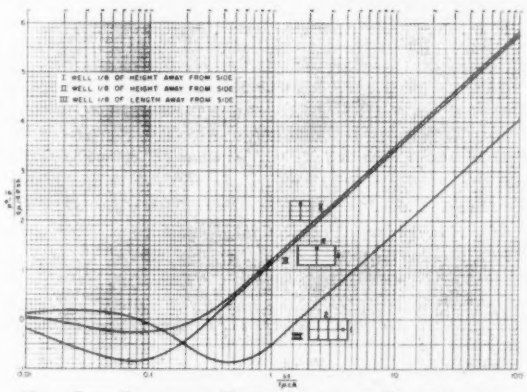

FIG. 7 — PRESSURE FUNCTION IN A SQUARE AND 2:1 RECTANGLE.

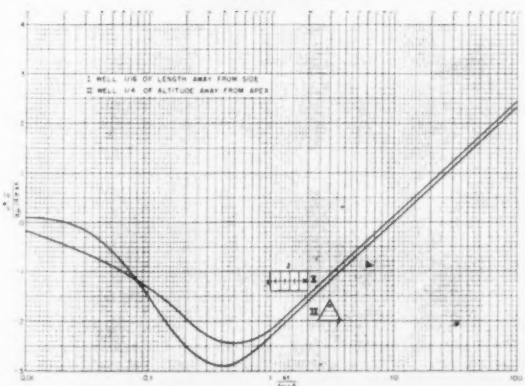

FIG. 8 — PRESSURE FUNCTION IN A 2:1 RECTANGLE AND AN EQUILATERAL TRIANGLE.

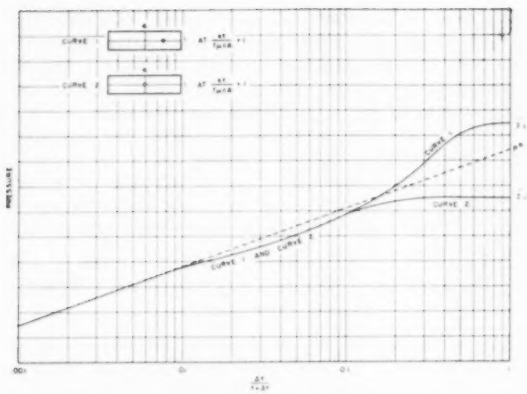

FIG. 9 — ILLUSTRATIVE PRESSURE-BUILDUP CURVES.

In Appendix III, it is shown that the rate of pressure decline approaches a value q/cfv in any drainage volume. Thus for any two wells j and k in the reservoir at the steady state when $\partial p/\partial t$ is constant,

$$\frac{q_j}{fv_j} = \frac{q_k}{fv_k} \quad \ldots\ldots\ldots \quad (2)$$

Thus at steady state the drainage volumes in a bounded reservoir are proportional to the rates of withdrawal from each drainage volume. From this it can easily be seen that a well producing at rate q_j from a reservoir of total volume v_t drained by wells with a total rate of off-take q_t, has a relative drainage volume at steady state given by

$$\frac{v_j}{v_t} = \frac{q_j}{q_t} \quad \ldots\ldots\ldots \quad (3)$$

This equation may be used to estimate the drainage volume of each well in the bounded reservoir at steady state. Thus, after determining the average pressure in each of these volumes by use of pressure build-up data and the $p^* - \overline{p}$ curves (details of the method are discussed below), the over-all volumetric average may be easily computed with the aid of (3). Although Equation (3) applies strictly at steady state only, it will be shown below that it also furnishes a satisfactory approximation for purposes of determining average reservoir pressure at times prior to steady state.

After steady state is reached the drainage volumes remain constant as long as the rates of withdrawal remain constant. If any one rate is altered, a transient stage is introduced throughout the reservoir. Only after the reservoir has been drained for a certain time by the changed rates will the drainage volumes become constant again at the new steady state. However, it is believed that for purposes of approximating average reservoir pressure the drainage volume may generally be calculated with sufficient accuracy from Equation (3) regardless of production time.

Results from additional work, as yet unpublished, have suggested that the shape of the drainage areas may be estimated as follows: (1) Draw a line between the well in question and adjacent wells. Locate the position of the drainage boundary along these lines at distances d_i from well i, where

$$\frac{d_i}{d_{ij}} = \frac{q_i}{q_i + q_j} \quad \ldots\ldots\ldots \quad (4)$$

d_{ij} being the distance from well i to well j, and q_i and q_j the production rates of wells i and j. (2) Sketch in all drainage areas and check to determine whether they satisfy Equation (3). If they do not, adjust the drainage areas until they do. If the drainage area of a strong producer must pass between that of two other wells in order to satisfy (3), in general it will tend to pass between the drainage areas of poor producers or will tend to finger toward a sparsely drilled section.

In order to test these methods, the true average reservoir pressure was computed from the amount of production for several simulated multiwell reservoirs of simple shape. The true average was then compared with the average pressure obtained by use of the correction charts in Figs. 2 to 8. In each case the drainage volume of each well in the multiwell reservoir

TABLE 1 — AVERAGE PRESSURE IN A SIMULATED FOUR-WELL RESERVOIR

	$kt_3/f\mu cA_t$	$kt_4/f\mu cA_t$	$kt_1/f\mu cA_t$	$kt_2/f\mu cA_t$	Computed from Charts $\overline{p}_1$ atm	$\overline{p}_2$ atm	$\overline{p}_3$ atm	$\overline{p}_4$ atm	$\overline{p}$ atm	True $\overline{p}$ atm	Error atm
Period A	0				250				250	250	0
	.1	0			246.23				246.23	246.23	0
Period B	.2	.1			238.45	238.96			238.71	238.69	+ .02
	.5	.4			215.44	216.07			215.75	216.07	− .32
	.7	.6	0		200.96	200.96			200.96	200.99	− .03
Period C	.72	.62	.02		198.16	192.49	205.03		198.56	198.73	− .17
	.8	.7	.1		190.22	185.90	191.57		189.23	189.68	− .45
	1	.9	.3	0	167.87	165.47	166.22		166.52	167.06	− .54
Period D	1.01	.91	.31	.01	160.15	163.45	164.14	174.25	165.50	165.55	− .05
	1.25	1.15	.55	.25	128.70	129.33	129.36	130.02	129.35	129.36	− .01
	1.5	1.4	.8	.5	91.60	91.66	91.66	91.69	91.63	91.66	− .03
	1.75	1.65	1.05	.75	53.93	53.96	53.96	53.96	53.95	53.96	− .01
	2	1.9	1.3	1	16.26	16.26	16.23	16.23	16.25	16.26	− .01

NOTES: $q\mu/4\pi kh = 3$ atm in each well. All wells produce at the same rate but for different times. Drainage areas during each period are estimated using Equation (3). Then drainage boundaries are sketched in, as above. The following models were then selected to simulate the effect of these boundaries during each period:

A) One well draining the square — curve III, Fig. 3.
B) Two wells draining the square — curve III, Fig. 4 for each well.
C) Three wells draining the square — curve I, Fig. 3 for wells 2 and 3; and curve III, Fig. 4 for well 1.
D) Four wells draining the square — curve I, Fig. 3 for each well.

TABLE 2 – DETERMINATION OF DRAINAGE AREA

(1)	(2)		(3)	(4)	(5)	(6)	(7)
Well	Average Rate January 1950 tank bbl/day	Average Rate January 1950 res. bbl/day	v_j/v_t	Net Sand ft	$\frac{v_j}{v_t h_j}$ ft x 10^2	A_j/A_t	fv_j cc
1	39	47	.156	58	2.69	.205	1.76×10^{11}
2	33	40	.132	51	2.59	.198	1.49×10^{11}
3	28	34	.113	68	1.66	.126	1.28×10^{11}
4	151	181	.599	97	6.17	.471	6.77×10^{11}
		302	1.000		13.11	1.000	

v_t, volume of matrix and pores in reservoir estimated to be 1.00×10^{12} cc
Porosity = .174, interstitial water = .35
Net hydrocarbon-filled volume = $.174(1 - .35)\ 1.00 \times 10^{12}$
$= 1.13 \times 10^{12}$
$= fv_t$
and $fv_j = 1.13 \times 10^{12}\ (v_j/v_t)$

was obtained from Equation (3). The pressures p^* were obtained by the method of images given in Appendix II. A typical result is shown in Table 1.

Four periods are considered in Table 1. In period A, only well 1 is producing. At the end of 0.1 unit of dimensionless time, well 2 begins producing and period B begins. In period C, three wells produce and in period D, all four wells produce for times indicated in Table 1. At each value of time the value of p^* at each well was computed using the method of images discussed in Appendix II. Then, using Figs. 3 and 4, as indicated at the bottom of the table, values of $\bar{p}$ were obtained for each well and the over-all value for average pressure computed using Equation (3). The true value of $\overline{p}$ was obtained from the known cumulative production. Although transients were introduced every time a new well began producing, excellent agreement was obtained between observed and computed values for average pressure. These results (and others) are believed to justify use of Equation (3) for pressure estimation purposes even when the reservoir is known to be in a transient stage.

This example also indicates that the proposed method is accurate even though considerable regional migration may have occurred before a well is drilled. A theoretical analysis indicates that the proposed method should be exact when a steady state is reached and that the magnitude of the numerical error should, in general, be small in the transient period, as noted in this example.

It seems pertinent to note at this point that the average drainage volume pressure may vary over a bounded reservoir in a completely random manner. Drainage volumes of high average pressure may be mixed in any manner with drainage volumes of low average pressure. It is believed that the method of volumetric averaging suggested in this section is both simpler and sounder theoretically than a method based on "contouring" of well pressures.

APPLICATION OF THE METHOD

Determination of Drainage Boundaries

A map of the example field is shown in Fig. 10. Average production rates the month before shutting in are given in Table 2. From these rates the relative drainage volumes, v_j/v_t, shown in column (3) were computed using Equation (3). To compute the drainage areas it was assumed that the average thickness of each drainage volume was proportional to the thickness at the well, and that the constant of proportionality was the same for all areas. It may then be shown that

$$\frac{A_j}{A_t} = \left(\frac{v_j}{v_t}\,\frac{1}{h_j}\right) \div \left(\sum \frac{v_j}{v_t}\,\frac{1}{h_j}\right). \quad (5)$$

Thus, column (5) in Table 2 was obtained by dividing the items in column (3) by those in column (4). Column (6) was obtained by dividing column (5) by the sum of column (5) according to Equation (5).

TABLE 3 – DETERMINATION OF AVERAGE PRESSURE

Well	p^* psia	$\frac{q\mu}{4\pi kh}$ atm	q at res. cond. cc/sec	$\frac{kh}{\mu}$ darcy-cm/cp	fv_j cc x 10^{-11}	C atm^{-1}	Total Production tank bbl
1	3877	1.594	86	4.29	1.76	2×10^{-4}	4480
2	3858	.1870	74	31.5	1.49	2×10^{-4}	5640
3	3932	3.051	63	1.643	1.28	2×10^{-4}	1930
4	3787	2.047	330	12.83	6.77	2×10^{-4}	10,800

Well	t sec x 10^{-6}	$\frac{kt}{f\mu cA}$	Model	$\frac{p^* - \overline{p}}{q\mu/4\pi kh}$	$p^* - \overline{p}$ psi	$\overline{p}$ psia	v_j/v_t	Volumetric Avg. Press.
1	9.94	1.21	2:1	1.76	41	3836	.156	
2	14.77	15.6	2:1	4.27	12	3846	.132	
3	5.96	.383	4:1	.11	5	3927	.113	
4	6.17	.585	2:1	1.90	57	3730	.599	
								3784

After the relative areas A_j/A_t were obtained, the drainage boundaries were sketched in and adjusted, as shown in Fig. 10, until each area was of the correct proportion.

Also shown in Table 2 are the quantities fv_j. These quantities are obtained by estimating a value for the total hydrocarbon-filled pore volume, fv_t, and multiplying this quantity by v_j/v_t. After the pore volume is obtained from a material balance analysis (which is usually the end object of determining the average pressure) these values may be refined.

Determination of Dimensionless Production Time

The essential steps in determining $kt/f\mu cA$ are shown in Table 3. One of the buildup curves is shown in Fig. 11. By straight-line extrapolation on the semi-log plot, a value of p^* was obtained for this well. Values of p^* obtained in the same way from other buildup curves are shown in Table 3. Values for the corrected production time t were obtained, as suggested by Horner,[2] by dividing the total amount of fluid production by the rate of production just before shutting in. After computing the slope of the straight-line section of each buildup curve, values of $q\mu/4\pi kh$ in atmospheres were obtained from

$$\frac{q\mu}{4\pi kh},\ \text{atm} = \frac{\text{slope, psi}}{14.7\ (2.303)}.$$

From all these quantities, values for $kt/f\mu cA$ were calculated by noting that

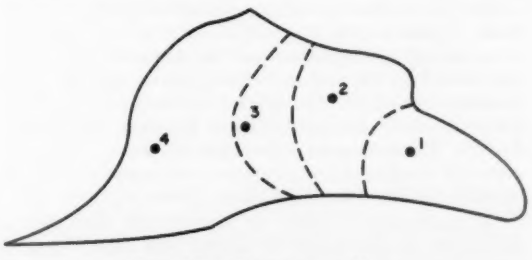

FIG. 10 — RESERVOIR MAP.

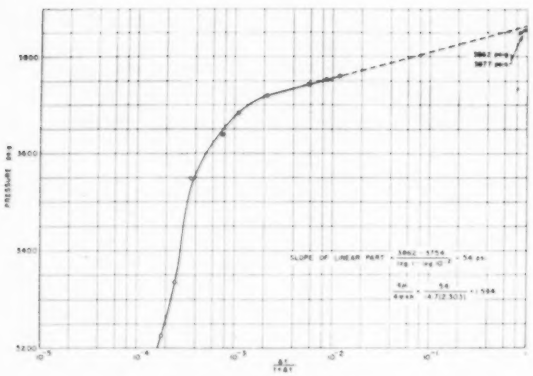

FIG. 11 — PRESSURE BUILDUP CURVE, WELL NO. 1.

$$\frac{kt}{f\mu cA} = \frac{kh}{\mu}\left(\frac{1}{fv_t}\right)\frac{1}{c}(t) \quad .$$

The next step is to select models whose shapes are most like those of each drainage area. It is believed that applicable models may be obtained in most instances by finding the rectangular figure with the length to width ratio about that of the irregular area, and with similar well placement in the rectangular area. The most critical point in the selection is the relative nearness of the well to the closest side. This should be relatively the same in the model as in the real figure. The divergence between the shapes some distance from the well should affect the results very little.

In the example case, drainage area 1 was considered to be like a 2:1 rectangle lying on its long side, with the well on the central long axis, but not on the central short axis, as indicated in Table 3. Drainage area 2 was considered as a 2:1 rectangle standing on its short edge. Drainage area 3 was taken as a 4:1 rectangle on its short edge with the well off center as indicated in Table 3. For drainage area 4, the long tip at the bottom left was considered to be partially balanced by the thinning to the top, and this area was also considered as a 2:1 rectangle on end.

After the model for each drainage area was selected, values for $(p^* - \overline{p})/(q\mu/4\pi kh)$ were read from the appropriate curve at the correct dimensionless time. Values of $\overline{p}$ were then obtained and, using the values of v_t/v_t, volumetrically averaged to give an over-all average reservoir pressure of 3,784 psia.

DISCUSSION AND CONCLUSIONS

An important question is "How does one take into account drainage volumes in which there are no pressure data?" To answer this question, it is suggested that a plot of average pressure against relative drainage volume may allow the missing pressures to be estimated. Such a plot has a theoretical basis if the reservoir is reasonably homogeneous and the shape of each drainage boundary is roughly equivalent in its effect on pressure behavior. To obtain the average reservoir pressure when the permeability variation, horizontalwise, is great, enough representative wells should be surveyed to allow a representative volumetric average to be taken on surveyed wells alone.

In conclusion, it may be stated that the method developed in this study is simply and easily applied when pressure-buildup data are available. It is believed that the method may be applied with good approximation to many bounded reservoirs which are met in practice. The suggested method of volumetric averaging of individual drainage zone pressures is believed simpler and of sounder theoretical basis than the older method of averaging based on contours of well pressure.

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SUMMARY OF APPENDICES*

APPENDIX I

Pressure Behavior in a Circular Reservoir

The basic equation in this appendix is that obtained by Muskat[4] for the relation between the pressure in a well at the center of a circular reservoir and the production time. Equation (1) in the body of the report is obtained from this equation by first adding and subtracting a logarithmic term, and then using the principle of superposition. The expression which is plotted in Fig. 2 for the circle is also obtained in this way, the final result being

$$\frac{p^* - \overline{p}}{q\mu/4\pi kh} = \frac{3}{2} + ln\frac{4\pi T}{\gamma} + 4\sum\frac{\exp(-x_n^2\pi T)}{x_n^2 J_0^2(x_n)}$$

APPENDIX II

Pressure-Buildup Behavior in Non-Circular Boundaries

In this appendix the method of images is employed to determine the pressure behavior inside bounded reservoirs which have the shape of simple polygons. An exponential integral function is used to simulate the effect of production at a well on the pressure distribution in the reservoir. An infinite sum of images of this well is taken to obtain the effect of the reservoir boundaries. To obtain a more rapidly convergent series for large values of time, use is made of the theta functions.

APPENDIX III

Value of $\partial p/\partial t$ at Steady State

From the equations describing the pressure behavior in bounded reservoirs it is shown that at large time the rate of change of pressure with time is the same at every point within the reservoir. Applying the principle of superposition it is shown that this is also true when a reservoir contains more than one well. It is further shown that the rate of pressure decline approaches a value q/cfv in any drainage volume. ★★★

*The full text of the appendices is found in the preprints of this paper and will appear in Petroleum Transactions Volume 204. Reprints of these appendices in their entirety may be obtained by writing the office of the Journal of Petroleum Technology.

ESTIMATED EFFECT of VERTICAL FRACTURES on SECONDARY RECOVERY

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T. P. 3879

ABSTRACT

Potentiometric model studies have been made of vertically fractured reservoirs. All fractures originated at the well and extended into the reservoir for various distances. Studies were made to determine the areal sweep efficiencies for line-drive patterns. The areal sweep efficiency for the unfractured system studied was 70.6 per cent. It was found that if the vertical fracture was parallel with the direction of flood, the areal sweep efficiency may be considerably reduced, approaching zero in some instances. If the fracture was at right angles to the direction of flood, the areal sweep efficiency may be greater than that for the unfractured system. The sweep efficiency depends on the length and orientation of the fracture and direction of the flood. It is concluded that considerable effort should be made to determine the nature and direction of fractures before initiating a flooding program. Such information is required if the maximum sweep efficiency is to be obtained and channeling is to be reduced to a minimum.

INTRODUCTION

The recent development and application of fracturing techniques to petroleum reservoirs has served to focus considerable attention on the effect such fractures may have on secondary oil recoveries. The opinion has been expressed that fracturing may not alter appreciably the water flooding possibilities. Others have thought that channeling may occur and that the creation of fractures may serve to substantially reduce the possibilities of conducting a successful water flood in the reservoir

The purpose of this study was to obtain quantitative estimates of the effect of vertical fractures on the areal sweep efficiencies of line-drive flooding patterns. In presenting this work on vertical fractures, it is not to be inferred that the present fracturing techniques result in producing a vertical fracture. The types of fracture which are created are not known with certainty in every case. Some are believed to be horizontal, others inclined along bedding planes, and some data indicate vertical fracturing. Each fracture will probably exert a different influence on the sweep efficiency of the secondary recovery program; consequently each fractured well should perhaps be considered as a separate problem, requiring a careful analysis.

Preliminary work on the effect of fractures on producing capacity of a well indicated that for practical purposes many fractures may be treated as having a nearly infinite permeability This assumption appears to be valid in some instances where the permeability of the fracture is only 10 or 100 times greater than the permeability of the matrix. It is known to depend on the type, orientation and length of the fracture. In realization that fractures of only 0.01 in. width have calculated permeabilities near 5,000 darcys, it is believed that many fractures may be considered as of near infinite permeability without incurring serious error. Primarily for this reason this study was made with fracture analogs of very great permeability compared to the matrix.

FRACTURED SYSTEM ANALOG

The pattern sweep efficiencies reported here were obtained with the aid of a potentiometric model. The application of this type model for solving reservoir problems has been described in the literature.[1,2,3] The electrolyte reservoir was 20 in. wide by 30 in. long by approximately ½ in. deep. The liquid depth was constant, which corresponded to a constant permeability-feet product from the injection to the production well. The electrolyte reservoir was built to correspond to a unit in the line-drive pattern shown in Fig. 1. This figure shows part of an infinite array of wells having alternate rows of fractured and unfractured wells. The area within the dashed rectangle shows the area generally studied in the model.

In using the model to represent a fractured system, a thin strip of copper was soldered to the well or wells and the length and orientation of the strip was made to conform to the vertical fracture under consideration.

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office July 31, 1953. Paper presented at the Petroleum Branch Fall Meeting at Dallas, Oct. 19-21, 1953.

*Present address: Stanolind Oil and Gas Co., Tulsa.

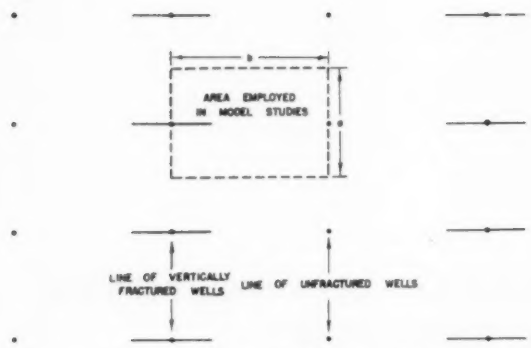

FIG. 1 — INFINITE ARRAY OF WELLS AS TREATED IN MODEL STUDIES.

PATTERN SWEEP EFFICIENCIES

VERTICAL FRACTURES PARALLEL TO DIRECTION OF FLOOD

The first types of fractures studied were those where the fractures originated at one well and extended directly toward the opposite well. This is shown in Fig. 2, where the streamlines and isopotentials for a particular vertically fractured system are indicated. The length of the fracture is 12.9 per cent of the distance to the opposite well. The isopotentials are numbered 0, 5, 10, etc. The streamlines are not numbered but are of approximately equal carrying capacity. It will be noted on Fig. 2 that a very low potential gradient existed about the fractured well.

The first isopotential represents only 5 per cent of the applied potential. At the unfractured well it will be noted that 40 per cent of the potential drop occurs within a very close distance to the well. Substantially radial flow was found to exist near the unfractured well. Of particular interest, perhaps, is the location of the 50 per cent or dividing isopotential line. This line which may be related to the approximate drainage radius during the final stages of primary depletion, is seen to be located very near the unfractured well.

Fig. 3 shows the flood fronts at breakthrough for the system described above. The flood fronts are shown for two conditions: (a) flooding from the fractured to the unfractured well, and (b) flooding from the unfractured to the fractured well. The areal sweep efficiency was found to be 63.8 per cent of the total area inclosed within the rectangle. The sweep efficiency was the same for conditions (a) and (b) above. The shape of the fronts differed, but the swept area was the same. The sweep efficiency of near 63 per cent is that which occurs at breakthrough, i.e., when the injected water first reaches the producing well. The production of water and oil to a high water-oil ratio would permit an increase in sweep efficiency over that shown. It is desired to point out that these studies were made at a mobility ratio of one.

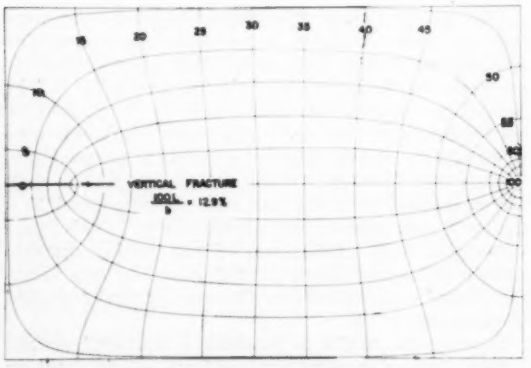

FIG. 2 — STREAMLINES AND ISOPOTENTIALS FOR A VERTICALLY FRACTURED SYSTEM (FRACTURE PARALLEL TO DIRECTION OF FLOOD).

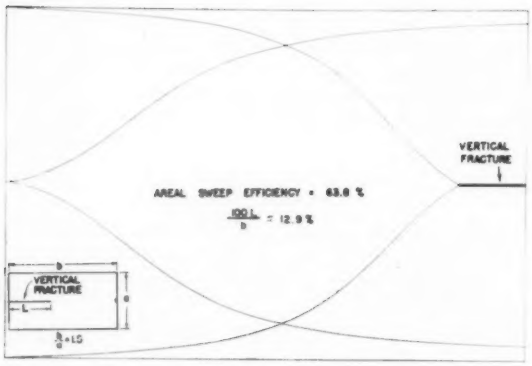

FIG. 3 — FLOOD FRONTS AT BREAKTHROUGH FOR A VERTICALLY FRACTURED SYSTEM.

A composite of flood fronts at breakthrough for vertically fractured systems having fractures of different lengths is shown in Fig. 4. The flow is from the unfractured well to the fractured well. Curve I shows the sweep efficiency when neither well was fractured; the sweep efficiency was 70.6 per cent. Curve III shows the sweep efficiency for the system in which the fracture length was 26.3 per cent of the distance between input and output wells, the corresponding sweep efficiency was 50.3 per cent. For Curves IV and V the fracture lengths were 36.1 and 44.6 per cent; the corresponding sweep efficiencies were 40.9 and 33.4 per cent respectively. It is perhaps obvious that the pattern sweep efficiency would be reduced to zero if the fracture connected the input and output wells.

Fig. 5 shows a composite of the flood fronts at breakthrough where the above fractured systems were considered to be flooded, in the reverse direction, i.e. from the fractured to the unfractured well. These flood fronts are shown to provide a comparison between the shapes

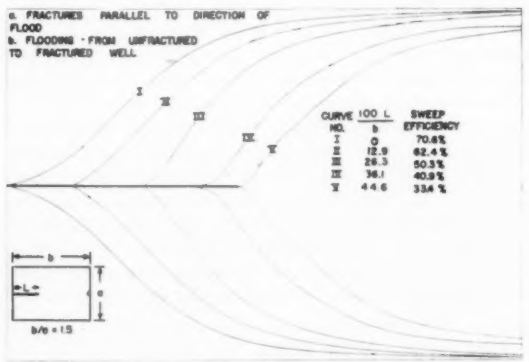

FIG. 4 — FLOOD FRONTS AT BREAKTHROUGH FOR VERTICALLY FRACTURED SYSTEMS.

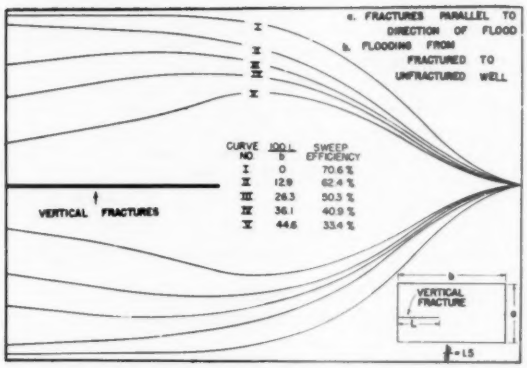
a. FRACTURES PARALLEL TO DIRECTION OF FLOOD
b. FLOODING FROM FRACTURED TO UNFRACTURED WELL
CURVE NO | 100 L/b | SWEEP EFFICIENCY
I | 0 | 70.6 %
II | 12.9 | 62.4 %
III | 28.3 | 50.3 %
IV | 36.1 | 40.9 %
V | 44.6 | 33.4 %
VERTICAL FRACTURES
VERTICAL FRACTURE
b/a = 1.5

FIG. 5 — FLOOD FRONTS AT BREAKTHROUGH FOR VERTICALLY FRACTURED SYSTEMS.

of the water-swept areas. It will be noted in this figure that the very long fractures produced a spearhead shape. As the fracture lengths were reduced, the shape of the flood fronts approached those of the unfractured system.

Fig. 6 shows a plot of the areal sweep efficiency versus fracture length where the flood is conducted parallel to the fracture. It will be noted that the sweep efficiency is seen to decrease as the fracture length increases. If the fracture extends half the distance between wells, a sweep efficiency of only 28 per cent may be expected. However, if an analysis of the fracture system indicated the possibility that such a fracture exists then studies should be made to consider the possibility of utilizing the fracture to increase the areal sweep efficiency. Means of accomplishing this are discussed below.

VERTICAL FRACTURES PERPENDICULAR TO DIRECTION OF FLOOD

Following the above work studies were made where the vertical fractures were perpendicular to the direction of flood. In this case the fracture (copper strip) was positioned along one end of the model. The opposite well was considered unfractured. Fig. 7 shows the streamlines and isopotentials for such a system. The fracture is 47.5 per cent of the distance between adjacent input wells. The isopotentials are shown 5, 10, 15, etc. The streamlines are not numbered but are of approximately equal carrying capacity. It will be noted on the figure that a very low pressure gradient existed near the fractured well. The 50 per cent isopotential was located very near the unfractured well. Figs. 2 and 7 and others prepared during the course of this work indicate the possibility of some fractured wells being able to drain large areas under favorable conditions.

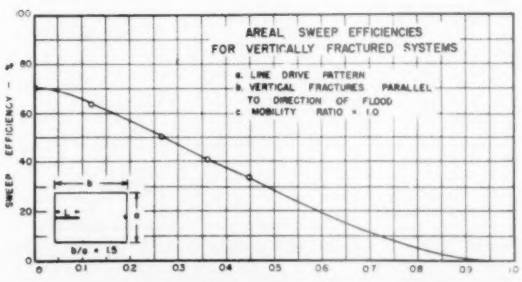
AREAL SWEEP EFFICIENCIES FOR VERTICALLY FRACTURED SYSTEMS
a. LINE DRIVE PATTERN
b. VERTICAL FRACTURES PARALLEL TO DIRECTION OF FLOOD
c. MOBILITY RATIO = 1.0
SWEEP EFFICIENCY - %
b/a = 1.5

FIG. 6 — AREAL SWEEP EFFICIENCIES FOR VERTICALLY FRACTURED SYSTEMS.

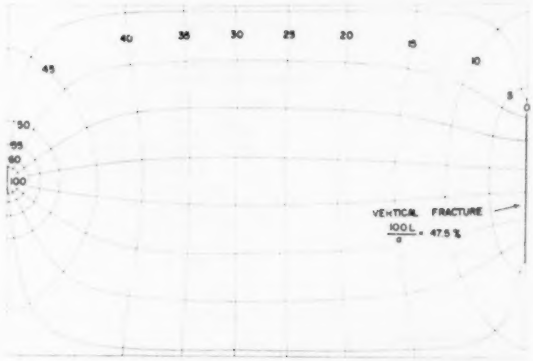

FIG. 7 — STREAMLINES AND ISOPOTENTIALS FOR A VERTICALLY FRACTURED SYSTEM (FRACTURE PERPENDICULAR TO DIRECTION OF FLOOD).

Fig. 8 shows the flood fronts at breakthrough for the fractured system shown in Fig. 7. The front on the right shows the flood front at breakthrough with the fractured well as the input well, and the front on the left shows the flood front when flooding in the reverse direction. The areal sweep efficiency was 84 per cent in each case. It will be noted that the nose of the flood front advancing toward the fracture was fairly blunt or rounded in comparison with the sharp nose advancing toward the unfractured well. This was due principally to the difference in flow conditions in these regions. Near the central portion of the fracture the flow and voltage gradient were nearly linear. Approximately radial flow existed near the unfractured well.

Fig. 9 is a composite of the flood fronts at breakthrough for vertically fractured systems in which the fracture is perpendicular to the direction of flood, and flooding is toward the fractured wells. Curve I shows the sweep efficiency for the unfractured system. Curves II, III, and IV show the flood fronts when the fracture length was 23.8, 47.5, and 95.0 per cent; the corresponding sweep efficiencies were 78.0, 84.0, and 87.5 per cent, respectively. It will be noted in this figure that as the fracture length increased the nose at breakthrough became progressively more rounded.

Fig. 10 shows the flood fronts at breakthrough for the same system as described by Fig. 9 except that the flooding is from the fractured to the unfractured well. The sweep efficiencies are identical with those having corresponding fractures shown in Fig. 9.

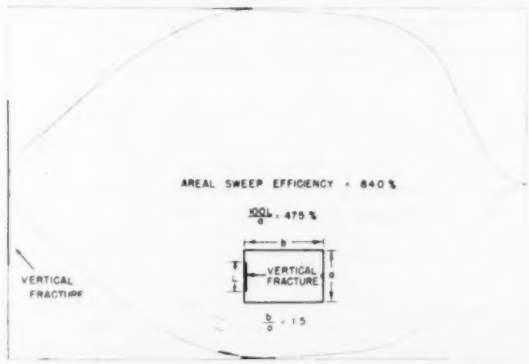

FIG. 8 — FLOOD FRONTS AT BREAKTHROUGH FOR A VERTICALLY FRACTURED SYSTEM.

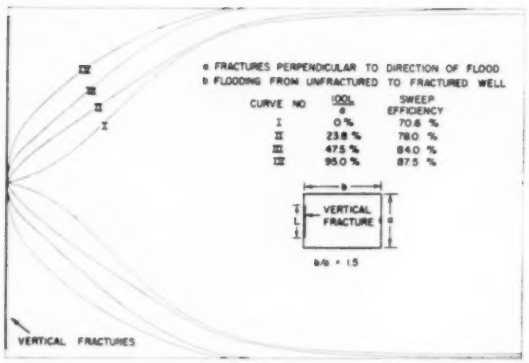

FIG. 9 — FLOOD FRONTS AT BREAKTHROUGH FOR VERTICALLY FRACTURED SYSTEMS.

Fig. 11 is a plot of areal sweep efficiency versus fracture length for vertically fractured systems in which the fracture is perpendicular to the direction of flood. These data were obtained for the line-drive pattern shown using a mobility ratio of one. It will be noted that as the length of fracture increased the areal sweep efficiency increased up to fracture lengths of about 80 per cent. At fracture lengths near 100 per cent, the sweep efficiency was slightly less than 90 per cent.

The above studies indicated the possible merit which might come about as a result of exploiting a vertically fractured system.

Other studies were made in which fractures existed at each well. These included fractures of the type shown in Fig. 12 where there were equal and opposite parallel vertical fractures. Fig. 12 shows the flood fronts at breakthrough for a specific case. The fractures were 23.5 per cent of the distance between adjacent input wells. An areal sweep efficiency of 80 per cent was observed. Fig. 13 is a plot of the areal sweep efficiency versus fracture length for systems having equal and opposite parallel vertical fractures. This figure indicates that such vertical fractures may permit very high sweep efficiencies to be obtained, approaching 100 per cent as the fracture length ratios approach unity. For fractures extending half the distance between adjacent input wells, sweep efficiencies of near 90 per cent may be expected.

A pattern was studied where two vertical fractures existed at one well. The fractures, which were at right angles, formed the cross configuration shown in Fig.

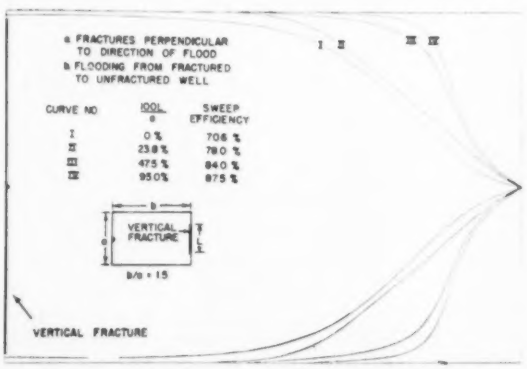

FIG. 10 — FLOOD FRONTS AT BREAKTHROUGH FOR VERTICALLY FRACTURED SYSTEMS.

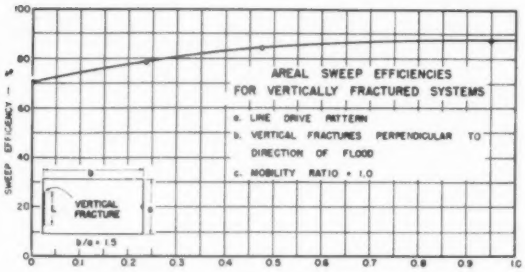
AREAL SWEEP EFFICIENCIES
FOR VERTICALLY FRACTURED SYSTEMS
a. LINE DRIVE PATTERN
b. VERTICAL FRACTURES PERPENDICULAR TO DIRECTION OF FLOOD
c. MOBILITY RATIO = 1.0
SWEEP EFFICIENCY, %
VERTICAL FRACTURE
b/a = 1.5

FIG. 11 — AREAL SWEEP EFFICIENCIES FOR VERTICALLY FRACTURED SYSTEMS.

14. In this case the length of the fracture was the same in each direction. The fracture length was 23.5 per cent of the distance between adjacent input wells or 15.7 per cent of the distance between input and output wells. This fracture pattern is of considerable interest in that it indicates how a second vertical fracture might be made to partially offset the deleterious effects of a first fracture. If only the fracture parallel to flow had been present, Fig. 6 indicates that a sweep efficiency near 61 per cent would have been obtained. If a second fracture could be created so that a cross was formed then the sweep efficiency might be increased to the 68.7 per cent shown on Fig. 14. These data tend to emphasize the significance vertical fracturing may have on areal sweep efficiencies of some secondary recovery programs.

A study was made to determine the areal sweep efficiency of the four well system shown in Fig. 15. It will be noted on this figure that the two wells on the left have vertical fractures extending directly toward the unfractured wells on the right. The length of these fractures was 23.5 per cent of the distance "b" shown in prior figures. The injection and production wells are labeled in the figure. The potential difference was the same between each set of input and output wells which corresponds to carrying the same pressure at each injection well in the reservoir. Under this condition the model study indicated that these particular fractured wells would take fluid 4.94 times the rate of the unfractured wells.

Fig. 15 shows that breakthrough will occur first between the two unfractured wells. When this occurs the invading fluid will have advanced only about half the distance between the unfractured wells. The swept area at breakthrough was 55.2 per cent. Several studies

FIG. 12 — FLOOD FRONTS AT BREAKTHROUGH FOR PARALLEL VERTICAL FRACTURES.

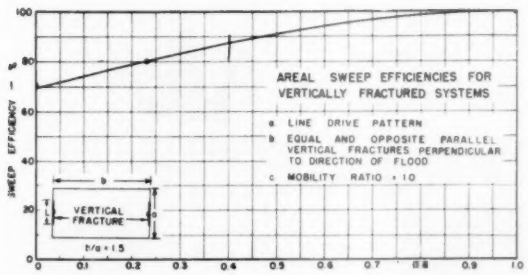
AREAL SWEEP EFFICIENCIES FOR VERTICALLY FRACTURED SYSTEMS
a LINE DRIVE PATTERN
b EQUAL AND OPPOSITE PARALLEL VERTICAL FRACTURES PERPENDICULAR TO DIRECTION OF FLOOD
c MOBILITY RATIO = 1.0
SWEEP EFFICIENCY, %
VERTICAL FRACTURE
b/a = 1.5

FIG. 13 — AREAL SWEEP EFFICIENCIES FOR VERTICALLY FRACTURED SYSTEMS.

were made of the well pattern shown in Fig. 15, and it appears entirely possible to achieve a considerably higher sweep efficiency by proper adjustment of the injection and production rates.

DISCUSSION AND CONCLUSION

The work reported here constitutes a part of the research program sponsored by the Texas Petroleum Research Committee on a study of fractured and heterogeneous reservoirs.

Potentiometric model studies have been made of the areal sweep efficiencies of vertically fractured, line-drive patterns at a mobility ratio of one. In every case the fractures originated at the well and extended into the reservoir for various distances. The areal sweep efficiency was found to vary from near 0 to 100 per cent, depending on the length and orientation of the fracture and direction of the water flood.

A decrease in areal sweep efficiency was obtained where the fracture was parallel to the direction of the flood. If the fracture extended half the distance between wells a sweep efficiency near 28 per cent might be expected for the particular pattern studied here.

An increase in areal sweep efficiency was obtained where the fracture was perpendicular to the direction of flood. Very high sweep efficiencies were obtained for the case of equal and opposite parallel vertical fractures. In this case theoretical areal sweep efficiencies near 100 per cent may be approached. For a given vertically fractured system a 90-degree change in the direction of the flood may alter appreciably the oil recovered at breakthrough.

It is suggested that a study be made of fractured

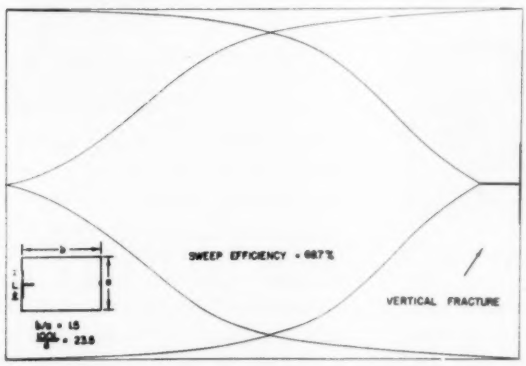

FIG. 14 — FLOOD FRONTS AT BREAKTHROUGH FOR A SYSTEM OF MULTIPLE VERTICAL FRACTURES.

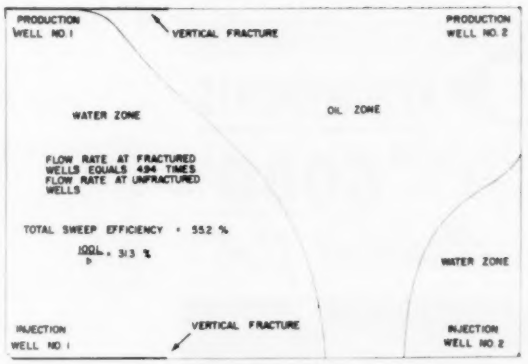
PRODUCTION WELL NO. 1
VERTICAL FRACTURE
PRODUCTION WELL NO. 2
WATER ZONE
OIL ZONE
FLOW RATE AT FRACTURED WELLS EQUALS 494 TIMES FLOW RATE AT UNFRACTURED WELLS
TOTAL SWEEP EFFICIENCY = 55.2 %
100L/b = 31.3 %
WATER ZONE
INJECTION WELL NO. 1
VERTICAL FRACTURE
INJECTION WELL NO. 2

FIG. 15 — FLOOD FRONTS AT BREAKTHROUGH FOR A VERTICALLY FRACTURED SYSTEM.

wells to determine the nature of the fractures prior to initiating a secondary recovery program. If a flooding scheme cannot be devised whereby the fractures are utilized to increase the sweep efficiency, then some consideration should be given to remedial measures.

The possible advantages which might accrue from the development of a directionally controlled vertical fracturing technique are indicated.

ACKNOWLEDGMENT

The authors wish to acknowledge the aid and encouragement of Robert L. Whiting, acting director of Texas Petroleum Research Committee, in conducting this study. Appreciation is expressed to the Texas Petroleum Research Committee for permission to publish the paper.

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DISCUSSION BY AUTHORS

The data and results which are presented in this paper were obtained on a potentiometric analyzer of a type which has been used in the past in some instances to estimate sweep efficiencies for water flooding programs.

The model as operated here shows the sweep efficiencies which would be expected if a uniform homogeneous reservoir consisting of an infinite array of the studied patterns could be operated at steady-state conditions. It is further required that the mobility ratio be one and that gravitational effects be entirely neglected. The indicated results shown in the paper apply only in such proportion as the flow in the reservoir corresponds to that in the model. Subsequent data which have been obtained on the effect of vertical and elliptical fractures on the five spot pattern efficiency indicate that each fractured pattern is unique and will require a special study. ★★★

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MEET the AUTHORS

LAWRENCE E. WILSEY, technical group leader with Stanolind Oil and Gas Co., was a petroleum engineering graduate of the University of California at Berkeley in 1947. He worked in Brownfield, Tex., and Fort Worth before being transferred to the research laboratories in Tulsa in 1949.

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FREDERICK M. PERKINS, JR., joined Humble Oil & Refining Co. in 1952, immediately after graduation from the University of Florida. He has worked on well logging and fluid mechanics in the Production Research Division of Humble.

CHARLES S. MATTHEWS is a senior chemist on the research staff at Shell Development Company's Exploration and Production Research Division in Houston. He received his PhD in chemistry from Rice Institute and worked for four years for Shell in San Francisco. Six years ago he moved to the Shell laboratories in Houston.

(Continued on Page 50)

THOMAS A. ATKINSON, member of the Branch Executive Committee, is now working with Douglas Oil Co. in Paramount, Calif. Formerly he was manager of production of Socony-Vacuum Oil Co. in Casper, Wyo. He is a mechanical engineering graduate of the University of California, having started to work for General Petroleum Corp. in 1926 while a high school student. From 1948 until 1951 he was manager of General's industrial relations department.

★

LESTER C. UREN, professor of petroleum engineering at the University of California, has retired after 42 years of teaching service. The author of books and articles on petroleum production organized the University's first petroleum engineering curriculum in 1915 and developed petroleum engineering courses that have become a pattern for similar programs in many other collegiate institutions. He will continue his professional and journalistic activities at the Mining Building, University of California, Berkeley.

★

W. T. Nightingale

WILLIAM T. NIGHTINGALE, president of Mountain Fuel Supply Co., has been elected president of the Salt Lake City Chamber of Commerce. A recent editorial in the *Salt Lake Tribune* paid tribute to the civic leader.

★

JOHN R. BRACK is now a petroleum reservoir engineer in the Midland office of Forest Oil Corp. Following his graduation from the University of Texas in 1949 he worked with Ohio Oil Co. in Midland until making this change on July 1. He is chairman of the Permian Basin Local Section.

J. V. Fredd

D. F. Taylor

Recent personnel changes at Otis Pressure Control, Inc., have brought promotions to JOHN V. FREDD and DONALD F. TAYLOR, JR. Fredd has been appointed project engineer of Otis Engineering Corp. Formerly he was Otis' senior design engineer. Taylor is now consulting engineer for Oklahoma and West Texas. Having been with Otis for 15 years, he formerly was manager of the special services department.

★

J. L. HEATH, of Schlumberger Well Surveying Corp., has been appointed Northern Rocky Mountain Division manager with offices at Casper, Wyo. He formerly was assistant manager of the Oklahoma Division, and now succeeds C. A. ROSENTHAL, who has been transferred to Denver as the Southern Rocky Mountain Division manager.

★

JOHN JANOVY has opened a consulting office in the Hales Building, Oklahoma City. He was a geologist for L. S. Youngblood prior to the opening of his consulting office on July 1.

★

J. J. McKetta

JOHN J. MCKETTA, JR., has resigned as editorial director of the *Petroleum Refiner* to return to the University of Texas as professor of chemical engineering. He had been a member of the chemical engineering staff at the University of Texas from 1946 until 1952 when he resigned to go with the *Petroleum Refiner*.

KENNETH G. MACKENZIE has been elected to honorary membership in the American Society for Testing Materials. He is now engaged in consulting work with offices in Westport, Conn., and Chicago, having retired from The Texas Co. on March 1 after 43 years of service. His work has been especially outstanding "for notable support and achievement in research and developing standards for petroleum products" stated the certificate presented to him.

★

LAWRENCE J. BECKMANN has opened a consulting office in the Oil Capital Building, Tulsa. He has been division geologist for the Union Oil Co. of California in Tulsa since 1952. Prior to that he worked for the Creole Petroleum Corp. in Venezuela and the Carter Oil Co. after 1935 graduation from the University of Texas.

★

E. L. DeGolyer

E. L. DEGOLYER has been elected to the Board of Directors of Dresser Industries, Inc., of Dallas. He is the senior member of the consulting firm of DeGolyer & MacNaughton.

★

IRVING DAGAN, who formerly was senior petroleum engineer at Coalinga, Calif., for Standard Oil Co. of California, is now senior engineer for the Kettleman North Dome Unit at Avenac, Calif.

★

ERNEST B. MILLER, JR., has been appointed a vice-president of Tide Water Associated Oil Co. in charge of the Southern Division. He has been with the company for 20 years, having served as chief petroleum engineer since 1947.

PETROLEUM BRANCH OFFICERSHIP ELIGIBILITY LIST

ARTICLE VIII of the By-Laws adopted September 10, 1953, provides that:
". . . To be eligible for election to the Executive Committee a member shall have had wide experience in the affairs of the Branch . . ."
". . . To be eligible for Chairman a member shall have three years of active service in the Branch, at least one of which shall have been as Chairman of a standing or special committee or as a member of the Executive Committee. . ."
". . . To be eligible for Vice-Chairman a member shall have had two years of active service in the Branch, at least one of which shall have been as chairman of a standing or special committee, or as a member of the Executive Committee, or a Chairman of a Local Section . . ."

The list below is of members who meet the specific provisions of eligibility for election to Chairman or Vice-Chairman. No attempt has been made to distinguish those who meet the non-specific portion of the eligibility requirements, i.e., "wide experience" and three years of active service." Data after each name represent the year and type of service, according to the code below.

The Pacific Petroleum and Illinois Basin Chapters have been considered Local Sections, within the intent of the By-Laws. The list may be incomplete with respect to the earliest years of the Branch (1922-1927), as full records on that period are not available. Please call any errors or omissions to the attention of the editor.

POSITION CODE

A	Chairman, Advertising	Nom	Chairman, Nominating
AC	Associate Branch Chairman	PE	Chairman, Production Engineering
Adm	Chairman, Admissions Committee	PG	Chairman, Production Geology
BT	Branch Treasurer	PP	Chairman, Papers and Programs
Ch	Branch Chairman	PR	Chairman, Production Review
CLS	Chairman, Local Section	Pro	Chairman, Progress
DT	Vice-Chairman, Drilling Technology	Prod	Chairman, Production
EC	Member, Executive Committee	PT	Chairman, Production Technology
Ec	Chairman, Education	Pub	Chairman, Publications
Eco	Chairman, Economics	RE	Refinery Engineering
EE	Chairman, Engineering Education	RVC	Branch Regional Vice-Chmn.
ER	Chairman, Engineering Research	SA	Chairman, Student Activity
Ge	Chairman, Geophysics	SC	Chairman, Special
NGT	Vice-Chairman, Natural Gas Technology	ST	Branch Secretary-Treasurer
Lc	Chairman, Lucas Fund	St	Chairman, Stabilizing
Me	Chairman, Membership	TC	Chairman, Technology
		TE	Transportation Engineering Chairman
		VC	Branch Vice-Chairman

Akins, D. W., Jr. — CLS 47
Alcorn, I. W. — Me 45, CLS 44, Ch 48, EC 48-49, Nom 49
Andrews, Paul — CLS 49, EC 49, VC 50
Armstrong, E. B. — CLS 47
Atkinson, Burton — CLS 48, Me 50
Atkinson, Thomas — CLS 47, EC 53
Aucoin, Riley — CLS 45

Ball, Douglas S. — Adm 53
Barkis, Bruce — A 52-53
Beal, Carlton — EC 46, ST 46, VC 48, SC 47-48
Beams, Robert J. — CLS 48
Beardmore, H. F. — CLS 41, RVC 44, Ch 46, EC 45-46-47
Beecher, C. E. — AC 30, Ch 31, EC 32-37
Beesley, Jack H. — Me 51, CLS 52
Bell, John S. — PE 46, CLS 44, EC 51-52-53
Bennett, E. O. — EC 35
Berlin, E. W. — PR 51-52
Berwald, William B. — CLS 45, EC 47
Bethancourt, Raoul — CLS 49
Blackwood, J. C. — CLS 53
Bradley, R. J. — Ec 48-49
Brown, Bob Diggs — CLS 51
Brown, J. W. — CLS 53
Brown, W. F. — CLS 50
Brownscombe, E. R. — Pub 48, CLS 53
Buckley, S. E. — CLS 42, PP 42, EC 44-45-47-48-49, AC 44
Bugbee, J. M. — Me 43, CLS 43, Pub 51

Calhoun, J. C., Jr. — EC 49-51, Ec 52-53
Camp, R. W. — RE 32
Carter, D. V. — PR 50, EC 52
Chaney, Preston E. — DT 53
Churchwell, R. M. — CLS 56
Coberly, C. J. — AC 40, EC 41-42
Coburn, R. W. — CLS 51
Cooley, H. M. — CLS 50
Cordell, J. C. — CLS 52
Corless, G. B. — EC 37-38-39, Ch 38
Coulson, J. L. — CLS 53
Covell, K. A. — CLS 38, PE 44
Craft, B. C. — Ec 45, ST 38-39-40, EC 44, PP 44, EC 48-49-50
Crawford, A. H. — CLS 53
Crichton, Jack A. — CLS 51

Dahlgren, E. G. — PR 47-48-49
Decker, Harold — CLS 47, EC 49-50-51
Dodson, Charles R. — EC 53
Dobyns, Rollie P. — CLS 53
Dooley, David L. — CLS-47
Duce, J. Terry — Prod 35-36-37-38-39-40-41
Dunlap, E. N. — CLS 49

Earlougher, R. C. — CLS 46, Pub 47, EC 50-51-52
Elkins, Lincoln — CLS 49, VC 51, CLS 53
Elkins, Lloyd — CLS 45, VC 47, EC 47-49-50, Ch 49, Nom 50
Estrabook, E. L. — EC 32

Ferguson, R. D. — CLS 53
Field, J. H. — CLS 51
Fisher, Eugene A. — CLS 46
Fisher, Gordon H. — CLS 47, Pub 49
FitzGerald, Norman D. — Ec 42-43-44
Fitzgerald, P. E. — CLS 40, ER 42, Me 44, Pub 46, VC 48, EC 48
Fohs, F. Julius — Ch 25-26
Ford, Kenneth B. — CLS 53
Fowler, Harry C. — ER 32, EC 36
Frick, Tom C. — CLS 47-49, EC 51-52
French, Richard W., Jr. — PT 48, VC 50, Ch 51, Nom 52

Garrison, A. D. — ER 41
Gaylord, E. G. — EC 35, Nom 39
Geis, W. H. — AC 38, EC 39-40-41, Ch 39
Gill, John D. — EC 45-46
Gilmore, R. B. — BT 50, PR 53
Glenn, Wayne E. — CLS 52
Gouldy, Roland — CLS 50, EC 53
Granberry, R. C., Jr. — CLS 50
Gray, George R. — CLS 52
Graybeal, L. W. — CLS 45
Greenidge, S. M. — EC 39
Griswold, E. H. — PE 31-32
Gruy, H. J. — CLS 53

Haider, M. L. — PE 38, Pub 43-44, EC 43-45-46, Ch 45, Nom 46
Halbouty, M. T. — CLS 39, Me 40
Hamilton, R. G. — CLS 43
Hamman, Cecil A. — CLS 49
Hammond, John P. — CLS 49, Pub 52, VC 53
Harlan, Don L. — CLS 49, PE 53
Haynes, W. P. — Prod 43-44
Hayward, J. T. — ER 36
Heithecker, R. E. — BT 51
Herald, Frank A. — Prod 33-34
Heroy, W. B. — EC 39-40-41-43
Hess, Robert M. — CLS 45
Higgs, Morton T. — CLS 45
Hill, H. H. — ER 30
Hill, Kenneth E. — Eco 52
Hocott, Claude R. — PP 45, AC 46, EC 46, Ch 53
Holmes, Joseph A. — CLS 47
Holsapple, L. W. — CLS 52
Howard, Raymond E. — CLS 52
Huntington, R. L. — ER 37-38

Jackson, Warren J. — CLS 48
Jones, N. N. — CLS 41
Justice, William H. — TC 53

Kantzer, Basil — CLS 51
Katz, D. L. — ER 39-40, PP 43, Ed 46-47, VC 53
Kaveler, H. H. — ER 45, PP 46, EC 46
Kelly, R. B. — EC 37-42, AC 41
Kelly, R. B., Jr. — CLS 52
Keplinger, C. H. — CLS 37, PE 42, RVC 46, EC 46
Kingman, D. G. — CLS 51
Kipp, Earl M. — TC 51
Knappen, Russell S. — EC 32-34
Knowlton, D. R. — EC 38-41
Kraus, Edgar E. — PG 47
Krause, H. M., Jr. — CLS 51

Langford, C. M., Jr. — CLS 40
Leeton, H. B. — CLS 50
Lehnhard, Phil J. — CLS 50
Leonard, W. W. — CLS 51
Leidholm, Clarence C. — SC 53
Lilley, E. R. — ST 30, Pub 45
Little, W. N. — CLS 50
Loomis, A. G. — ER 44
Long, H. L. — CLS 53
Love, R. W. — CLS 50
Lovejoy, John M. — Ch 27, LC 32-33-34-35
Lund, Richard J. — EC 51
Lyle, Henry — CLS 48

Manion, Peter P., Jr. — Me 47, CLS 48
Mangold, R. P. — CLS 53
Mapes, Clarel B. — EC 33-34
Marsh, H. N. — EC 32-33-36-37-38, Ch 36, Nom 40
Marshall, Dan L. — CLS 47
McCutchin, John A. — CLS 42
MacDonald, G. C. — CLS 53
McGirl, J. N. — CLS-51
McMillan, John R. — CLS 47, EC 50-51, VC 52
Mercier, V. J. — CLS 49
Millikan, C. V. — Ch 30, EC 33-36-40, Nom 38
Moore, Jack M. — CLS 51, Me 52
Moore, R. V. — ER 35, PE 37, AC 39, Ch 40, EC 41
Morris, W. S. — CLS 40, PP 40-41, EC 43-44-45, AC 42, Ch 44, Nom 45, SA 52-53
Morse, R. A. — Pub 53
Moulton, Gail F. — Prod 45-46, VC 49
Murrell, John H. — CLS 46, VC 47, EC 47-48-49-50
Muskat, Morris — PT 50, VC 52

Naramore, Chester — EC 44-45
Nowels, K. B. — ER 33
Nye, George L. — CLS 48

Osmond, Charles H. — RE 53
Ogden, L. A. — CLS 35

Parker, R. G. — CLS 52
Parks, Ernest K. — CLS 45
Parks, Mercer H. — CLS 46
Parsons, B. E. — EC 34
Penn, M. B. — Me 53
Petree, Ernest L. — CLS 50
Pishny, Charles H. — CLS 45
Pogue, J. E. — Ec 27, Ec 32
Pollard, Terry A. — Me 48, ER 49
Porter, L. E. — PE 43
Porter, W. W. II — CLS 47, EC 47-48
Posgate, James — CLS 48
Power, H. H. — PE 34, EC 35-36-40-51, Ch 35, Me 37, Nom 41, Ec 43-44
Powers, W. D. — CLS 50
Puckett, J. R. — CLS 53
Putnam, Murray — CLS 50
Pyle, H. C. — Ch 47, EC 47-48, Nom 48

LOCAL SECTION ACTIVITY CONTINUES in CALIFORNIA

Local Section activity is continuing with a full schedule of meetings through the summer months in California, although many of the local groups in other areas are not meeting during this season. The AIME Petroleum Forum and the Junior Petroleum Group held recent meetings, and an AIME All-Section meeting featuring AIME President Leo F. Reinartz is being planned.

John F. Dodge, consulting engineer, spoke on "The Petroleum Engineer as an Expert Witness in Litigation" at a recent AIME Petroleum Forum meeting. He discussed the qualifications, requirements, and ethics of an expert witness. He explained the difference between an ordinary witness and a professional witness in the presentation of technical evidence. Dodge drew from his own experiences in illustrating the various phases of testimony of a technical witness in litigation.

"Drain Hole Drilling as a Method of Increasing Recovery" was the topic of a symposium held before the Junior Group. C. William Zublin, Universal Engineering Co., Carl O. Spath, representing Oil Well Drain Hole Drilling Co., John Wentz, consultant, and Guy Abrahamson, Standard Oil Co., were the speakers.

Zublin and Spath outlined the objectives of drain hole drilling and the techniques employed by each of their companies. Wentz and Abrahamson, representatives of operating companies, drew from their experience to tell their experience with the application of drain hole drilling and the increase in recovery obtained.

On September 17, at an All-Section meeting, Leo F. Reinartz will be the principal speaker. Handling the arrangements for the meeting are Nick D'Arcy, Milton A. Loy, and George McMeans.

In August the AIME Petroleum Technology Forum meeting will feature a talk by George B. Mangold, chief engineer, Petroleum Engineering Associates, Inc. His subject will be "Application of Differential Thermal Analysis for Tonal Correlations." He will discuss its use as a formation correlation tool for both cuttings and cores and its potential value for explanation of electric log and core analysis through rapid mineral identification.

"Discussion of Rodless Bottom Hole Artificial Lifting Equipment" will be the subject for the August AIME Junior Petroleum Group meeting. Representatives from Byron-Jackson, Garrett, Kobe, Mid-Continent Supply, National Supply, and Sargent will present information on the design, engineering features and advantages of the various types of rodless bottom hole lifting equipment. A complete brochure of all of the rodless type pumps provided by the pump companies will be given to each member or guest present.

Ragland, Douglas	TC 52
Reistle, C. E., Jr.	EC 42, AC 43
Rhea, A. S.	CLS 42
Richards, Sidney B.	CLS 52
Rodgers, John A.	CLS 53
Schultz, Paul	Eco 50
Sheldon, Dean H.	CLS 48, EC 49-50-51
Shepherd, Jack M.	CLS 49
Sherborne, John E.	ER 46, EC 47-48-49-51, SC 46-47, VC 49, PT 49, Ch 50
Simmons, Fred E., Jr.	CLS 50
Smith, Roy H.	CLS 50
Smith, Veleair C.	AC 43
Speaker, W. F.	GT 53
Spice, W. H., Jr.	CLS 51
Spoor, H. C., Jr.	SC 49
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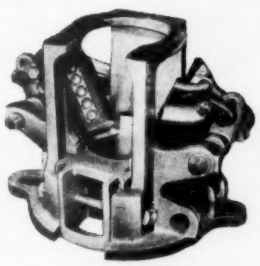
Stiles, William E.	BT 52-53
Stolz, Harry P.	AC 41, Ch 42, EC 43, Pro 45
Struth, H. J.	EC 32-47
Sullins, R. S.	CLS 53
Sullivan, J. H.	Adm 53
Suman, John R.	EC 32-33-34
Swanbeck, L. W.	CLS 52
Swensrud, Sidney A.	Ec 35-36-37-38
Teague, J. U.	CLS 41
Terry, L. F.	EC 39-40-41
Thies, Roland K.	CLS 52
Thronson, Lee J.	CLS 51
Trostel, E. G.	ER 43, PE 45, CLS 45
Tucker, Ivan	CLS 53
Turnbull, Paul	CLS 47, VC 51, Ch 52, EC 53, Nom 53
Umpleby, J. B.	PE 27, Ch 29, EC 32-47, SC 46
Uren, Lester C.	Ed 48
Van Duzee, E. N.	EC 52-53
Vance, Harold	PP 39, EC 41-42, ST 43-44
Vaughan, Harry D.	CLS 52
Vaughan, Jerry R.	CLS 53
Vietti, Wm. V.	CLS 37, EC 47-48
van Wingen, N.	PT 47, CLS 50
Walker, A. W.	CLS 39, PE 41
Waddill, Alfred W.	Me 46, CLS 51
Wadsworth, F. L.	CLS 53
Warner, C. A.	CLS 38, Me 39-41, AC 42, Ch 43, EC 44, Pro 46
Waszkowski, Henry	CLS 50
Watson, C. P.	AC 43, Prod 30
Weaver, P.	EC 39, Me 42, Ge 45-46
Wilcox, Stanley W.	CLS 44
Wilde, H. D., Jr.	PE 33, EC 33-34-35, Ch 34
Wrather, W. E.	EC 33-34, Ch 33
Wright, J. K., Jr.	CLS 51
Yates, G. L.	CLS 51, EC 52-53
Young, C. M.	EE 32-33
Zavoico, Basil	Prod 42, AC 43, RVC 43



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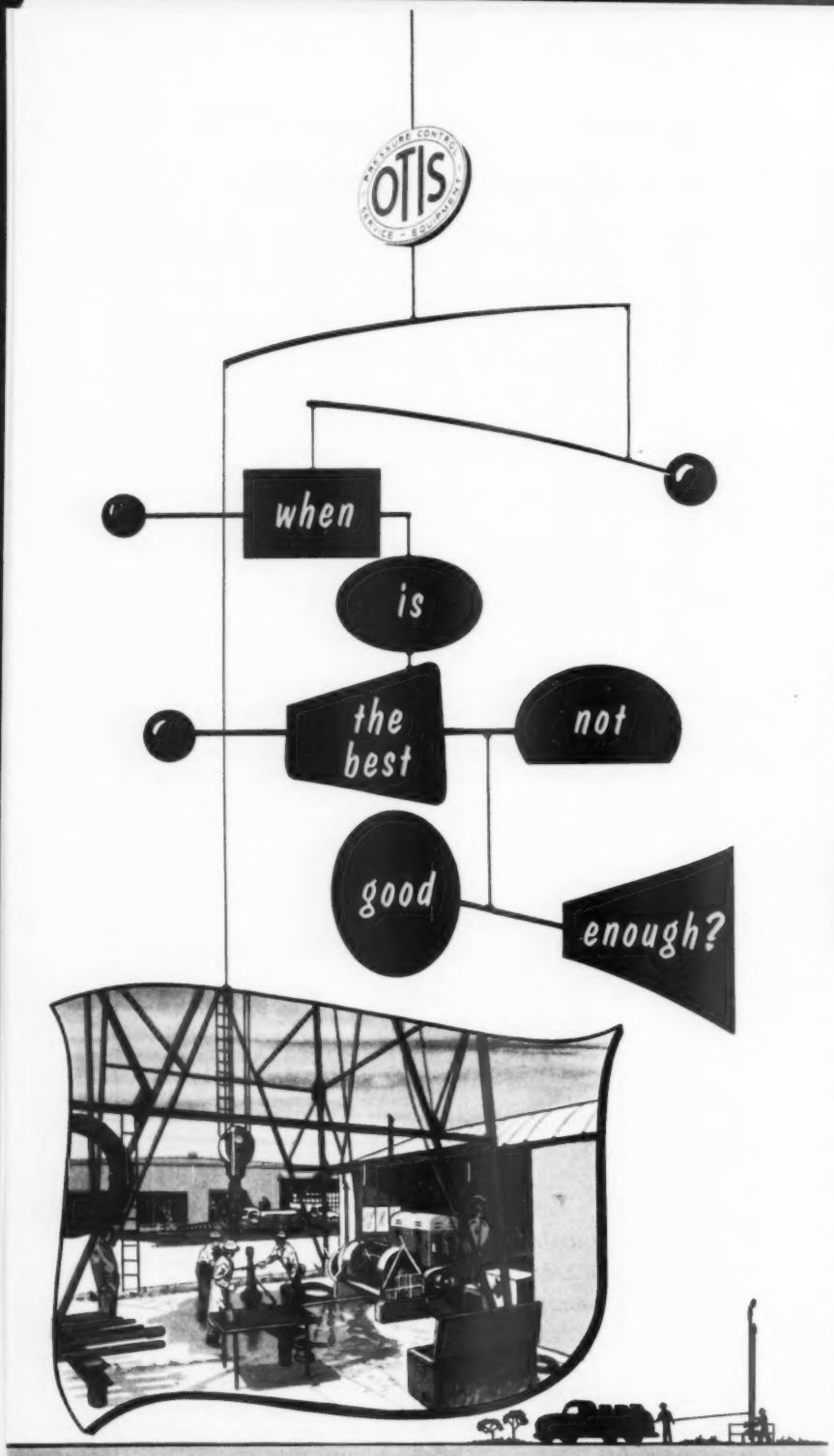

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Meet the Authors

(Continued from Page 46)

F. BRONS was born in the Netherlands and received his PhD in physics from the University of Groningen. From 1938 until 1941 he worked for B.P.M. (Royal Dutch Shell), and then entered the Army for a five year tour. He returned to B.P.M. in 1948 and in 1950 he joined Shell in Houston where he is senior reservoir engineer in technical services.

PIETER HAZEBROEK is a mathematician on the staff of the Geological Department of the Bataafsche Petroleum Maatschappij in The Hague, The Netherlands. He joined the staff of Royal Dutch Shell in 1938, following receipt of his PhD degree in mathematics and physics from the University of Leiden

PAUL B. CRAWFORD received his BS from Texas Technological College and his MS and PhD degrees in chemical engineering from the University of Texas. Prior to accepting his present position in 1952 as assistant director of Texas Petroleum Research Committee, he worked with American Cyanamide and Chemical Corp. and Magnolia Field Research Laboratories.

Formerly a research associate with Texas Petroleum Research Committee, ROYAL E. COLLINS is now a research engineer with Stanolind Oil and Gas Co., Tulsa. He holds degrees in physics from the University of Houston (BS) and A&M College of Texas (MS and PhD).

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 800 Fidelity Union Bldg., Dallas 1. These replies will be forwarded unopened and no fees are involved.

Replies to position coded W239 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

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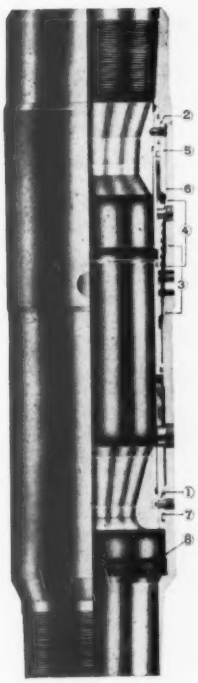

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Proposed for Membership, Petroleum Branch

TOTAL AIME membership on May 31, 1954, was 20,762; in addition 1,661 Student Associates were enrolled.

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The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member, A, Associate Member; S, Student Associate.

Arkansas
Lewisville — McDaniel, Fred Maeser (M).

California
Bakersfield — Walker, Gordon Allen (J).
Long Beach — Sarver, Harvey E. (J).
Piedmont — Whitson, Lloyd Robert Clark (M).
Ventura — Fahrenbach, Joseph Ray (J).
Whittier — Schuyler, Peter Treat (J).

Colorado
Denver — Wieder, Albert Henry (M).
Longmont — Hershey, Lloyd Ashton (J).
Sterling — Hansen, Harold Delmar (A).

Indiana
Evansville — Lobree, Hal S. (J); Yingling, Edward E. (M).

Kansas
Great Bend — West, Samuel Richard (M).
Independence — Layton, Dale E. (M)
Lawrence — Kurata, Fred (M).
Liberal — Ritchie, R. C. (J).

Louisiana
Lafayette — McKnight, Jerry Almond (R, C/S-S-M).
New Orleans — Draper, Robert Leon (J); Stone, Virgil DuWayne (M).
Ruston — Schlemmer, Alfred E. (J).

New York
Hastings-on-Hudson — Rees, Earl Mortimer (A).

Oklahoma
Ada — Simpson, Joe Weldon (M).
Bartlesville — Halderson, M. H. (M).
Norman — Branson, Carl Colton (M); Indra, Mohit Kumar (M).
Oklahoma City — Hicks, J. D. (R, C/S-S-M); McKee, Donovan S. (M); Stovall, William Stuart, Jr. (M).
Tulsa — Folger, Charles Junior (A); Minnich, Clark Southworth (J); Thomas, Kenneth H. (J); Turner, William Judson (R, M).
Wirt — Erskine, Herbert S. (R, C/S-S-M).

Pennsylvania
Philadelphia — Pew, Joseph Newton, III (M).

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Abilene — Buckles, Fred C. (A).
Amarillo — Morris, Edward S. (M).
Arlington — Price, Vernon (J).
Austin — Makhuli, Elias N. (J).
Bellaire — Gibbons, Leland Homer (M).
Cisco — Hitt, Harold Lee (J).
Dallas — Clay, Thomas Weldon (C/S-A-M); Jordan, Dewey Alfred (M); Kemp, Charles Ervin (A); McKaye, Maxwell Stanley (J).
Eastland — Gourley, Jack (M).
Fort Worth — Caldwell, Blake Marable (M); Clarke, Alex, Jr. (R, M); Gideon, Leroy (M).
Houston — Christensen, Peter John (M); Greenwald, William James (M); Parish, Robert Underwood, (J); Peaceman, Donald William (J); Scott, Floyd Logan, Jr. (M); Winkler, Herald Warren (M).
Iraan — Waggoner, Jack Nelson (M).
Midland — Guernsey, Arthur Taylor (M); Mannon, Alfred Thomas, Jr. (J).
Monahans — Hembree, Loy Marion (J).
Odessa — Nichols, Thomas Jerry (J); Walker, Robert Wendell (J).
Phillips — Ziser, J. A. (J).
San Antonio — Loring, Richard Ray (M).
Vanderbilt — Howard, John Darvin (M).

Wyoming
Casper — Lundberg, William Dow (M); Weger, Gene La Vern (M).
Thermopolis — Hoffman, George William, Jr. (J).

Brazil
Belem — Koch, Herman Joseph (M).

Canada
Edmonton, Alta — Loan, Aman Ullah (J).

Peru
El Alto — Lavado, Lucio Emeberto (J).

Venezuela
Caracas — Autric, Andre M. S. C. (M); Tribbey, Roy Jackson, Jr. (C/S-J-M).

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In order that publications and correspondence may reach you promptly, the Petroleum Branch, AIME, should be advised as soon as possible of any change in your address, *preferably a month before the change becomes effective.* For the AIME directory and for the Personals column of the JOURNAL OF PETROLEUM TECHNOLOGY, additional information is desired. The form below is provided for your convenience, and should be sent to Petroleum Branch, AIME, 800 Fidelity Union Bldg., Dallas 1, Tex.

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New Address_____
for
Publications_____

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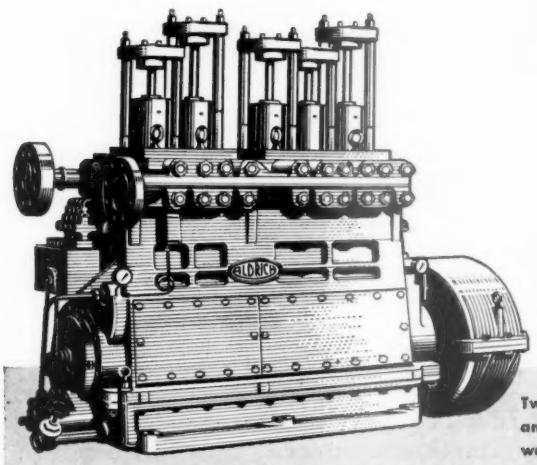

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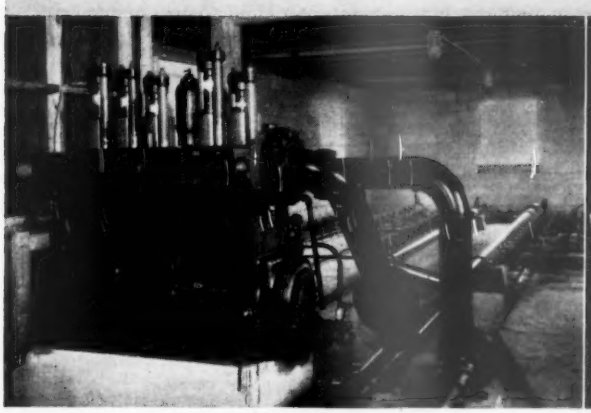
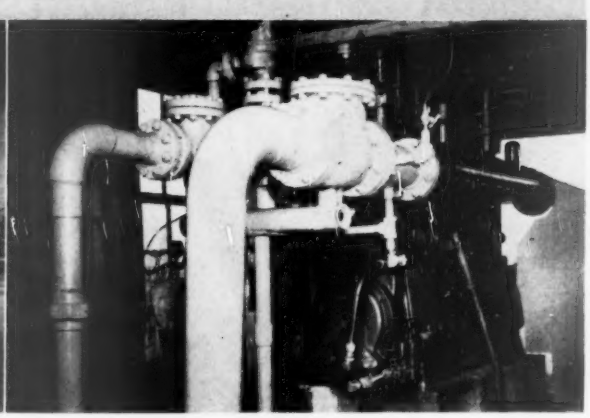
Two Aldrich Direct Flow Pumps on the job on water flood operations. At left is an Aldrich 5" stroke motor-driven Quintuplex Pump used for pumping salt water at the Osage #2 property of Winona Oil Company, Flat Rock, Okla. On the right is an installation at Skiles Oil Company, Mt. Carmel, Ill., where a similar Aldrich unit pumps fresh water at 120 gpm against 1450 psi.





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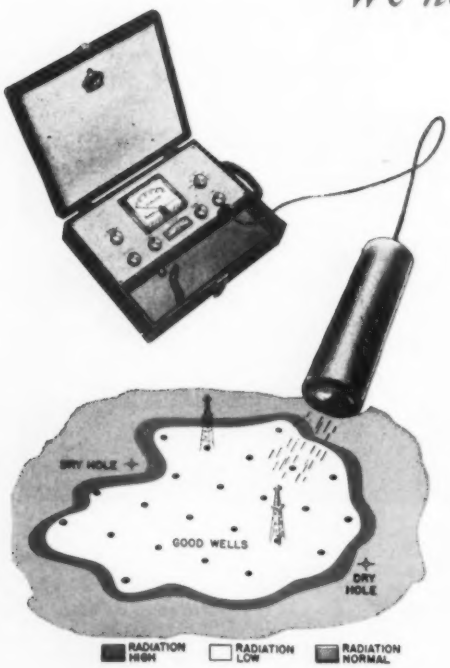

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AIME Petroleum Branch Meeting Dates Established

The dates and locations of the Petroleum Branch Fall Meetings and the Annual AIME Meetings have been established for future years.

The Petroleum Branch meets each October in oil country. The all-AIME Meeting is held in February in New York City on even years and in other cities serving a large number of members on odd years.

The schedule:

1954 — October 18-20, Petroleum Branch Fall Meeting, Plaza Hotel, San Antonio, Texas.

1955 — February 13-17, Annual AIME Meeting, Conrad Hilton Hotel, Chicago.

1955 — October 2-5, Petroleum Branch Fall Meeting, Roosevelt Hotel, New Orleans, Louisiana.

1956 — February 19-23, Annual AIME Meeting, Hotel Statler, New York City.

1956 — October 14-17, Petroleum Branch Fall Meeting, Biltmore Hotel, Los Angeles, California.

1957 — February 24-28, Annual AIME Meeting, New Orleans, Louisiana.

1958 — February 16-20, Annual AIME Meeting, Hotel Statler, New York City.

1959 — February 15-19, Annual Meeting, San Francisco, California.

1960 — February 14-18, Annual AIME Meeting, Hotel Statler, New York City.

1961 — February 19-23, Annual AIME Meeting, St. Louis, Missouri.

'55 BRANCH OFFICERS DECLARED ELECTED

The nominees for Petroleum Branch offices for 1955 have been declared elected. No additional nominations were made to those offered by the Branch Nominating Committee by the deadline of August 15; therefore, balloting was not necessary. They will take office in February, 1955.

Robert B. Gilmore, senior vice-president of DeGolyer and MacNaughton of Dallas, will succeed John R. McMillan as Petroleum Branch chairman. Vice-chairman will be Phil J. Lehnhard, field chairman of the East Texas Engineering Association, Kilgore, Tex., and G. Latham Yates, consulting petroleum engineer and a senior member of the firm of Amstutz and Yates, Inc., Wichita, Kan.

George R. Gray, manager of the Gulf Coast Sales and Service Laboratory of the Baroid Sales Division, National Lead Co., Houston, and Earl M. Kipp, Jr., chief petroleum engineer for The California Co., New Orleans, will take office as new Executive Committee members for 1955.

New Petroleum Section Conditionally Approved In New York City Area

The AIME Board of Directors has conditionally approved the formation of the New York Petroleum Section, which will overlay the New York Local Section in area. The approval of the Executive Committee of the New York Local Section and the working out of arrangements involving its cooperative function are the conditions of the Board's actions.

The group plans to start regular meetings in September or October, if final approval is received. John R. Suman, vice-president of Standard Oil Co. (N.J.) was the guest speaker at their organizational meeting.

Officers of the proposed Section are H. E. McAuliffe, Jr., Socony-Vacuum Oil Co., chairman, and M. J. Sladic, Arabian-American Oil Co., secretary-treasurer. Executive Committee members are D. B. Boese, Socony-Vacuum Oil Co., C. R. Dodson, National City Bank of New York, J. K. Reynolds, Chase National Bank, and T. L. Tapp, California-Texas Oil Co., Ltd.

The area to be covered by the section will approximate a 50-mile radius from Times Square.

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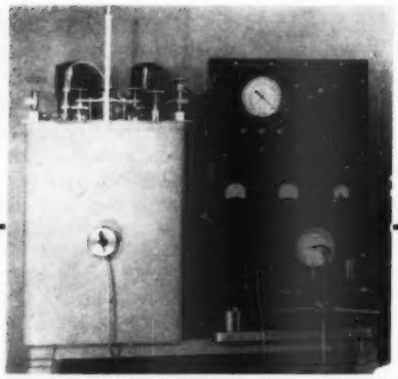

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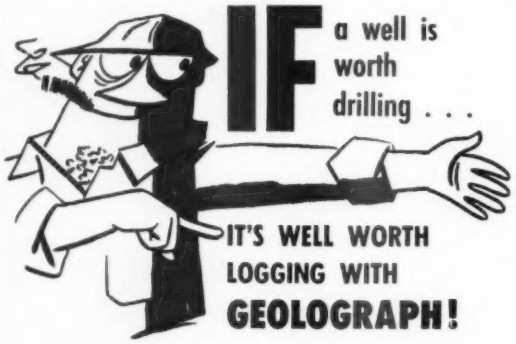

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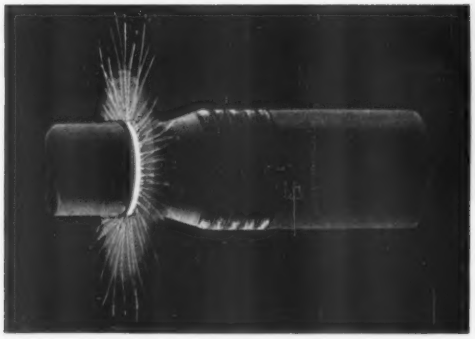

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